APPENDIX B: FIGURES

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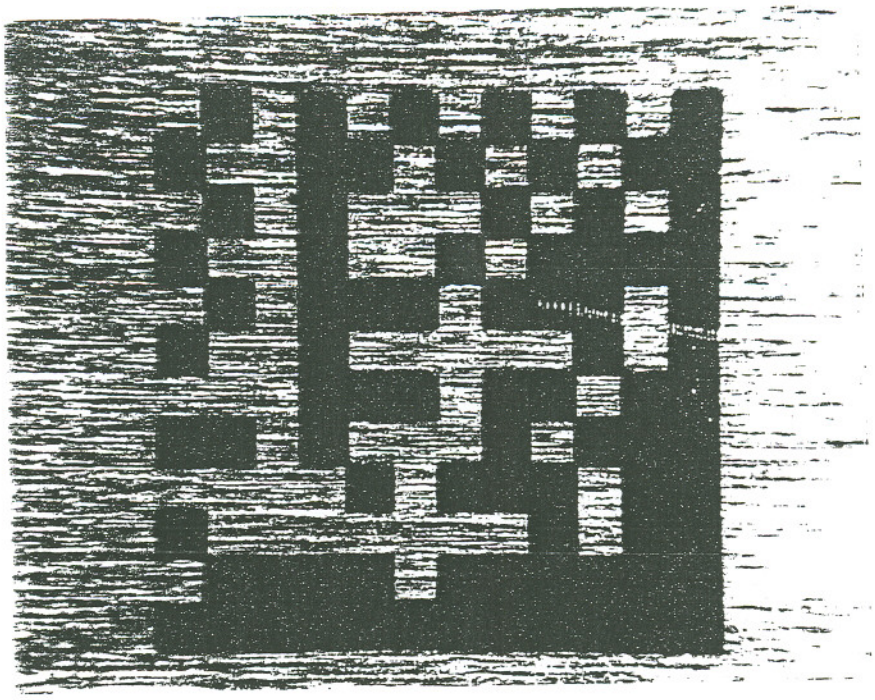


Fig. 1: Test 1, 17-4 PH, as received. 13x

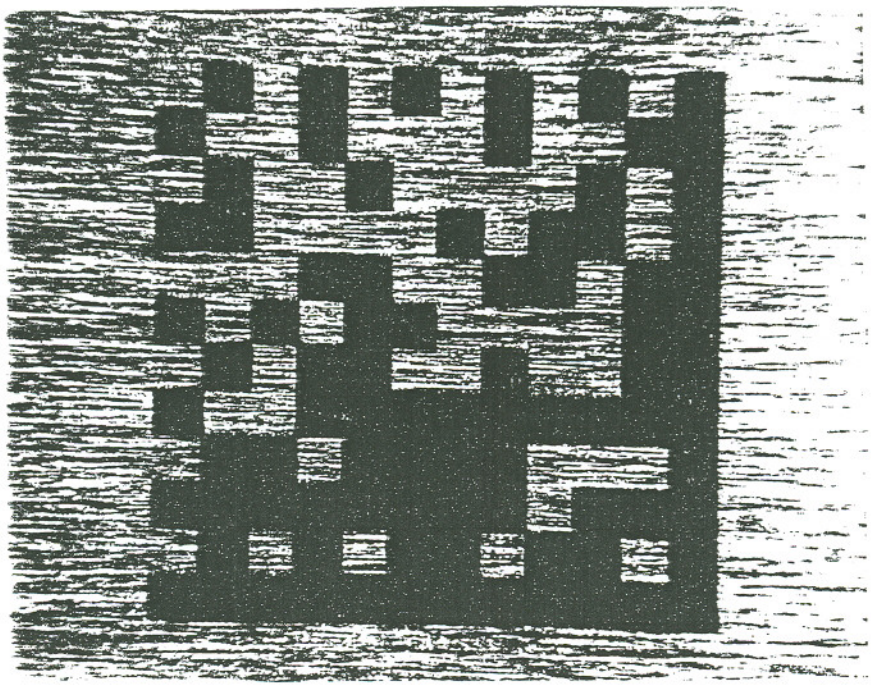


Fig. 2: Test 2, 17-4 PH, as received. 13x

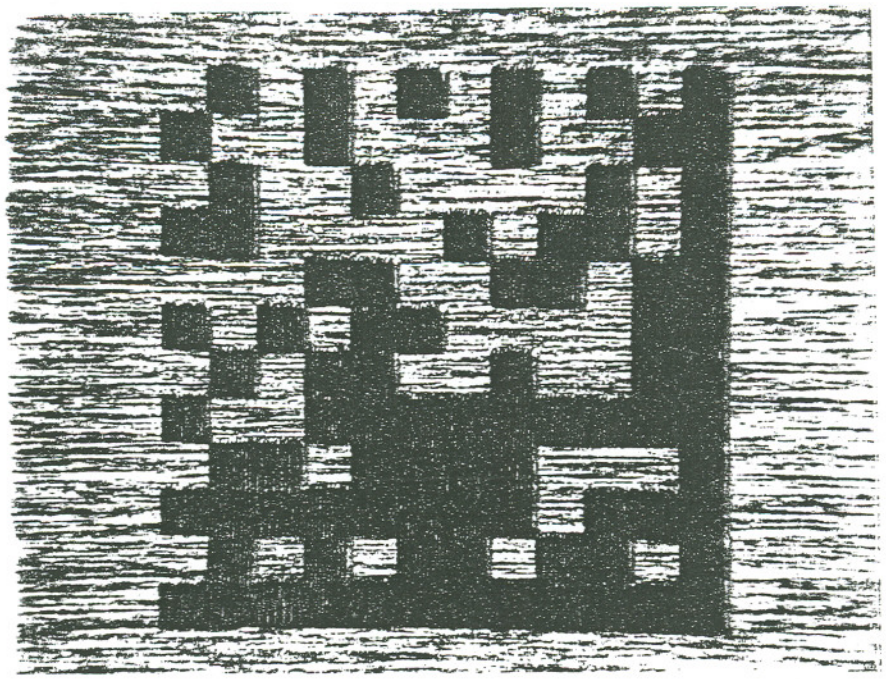


Fig. 3: Test 3, 17-4 PH, as received. 13x

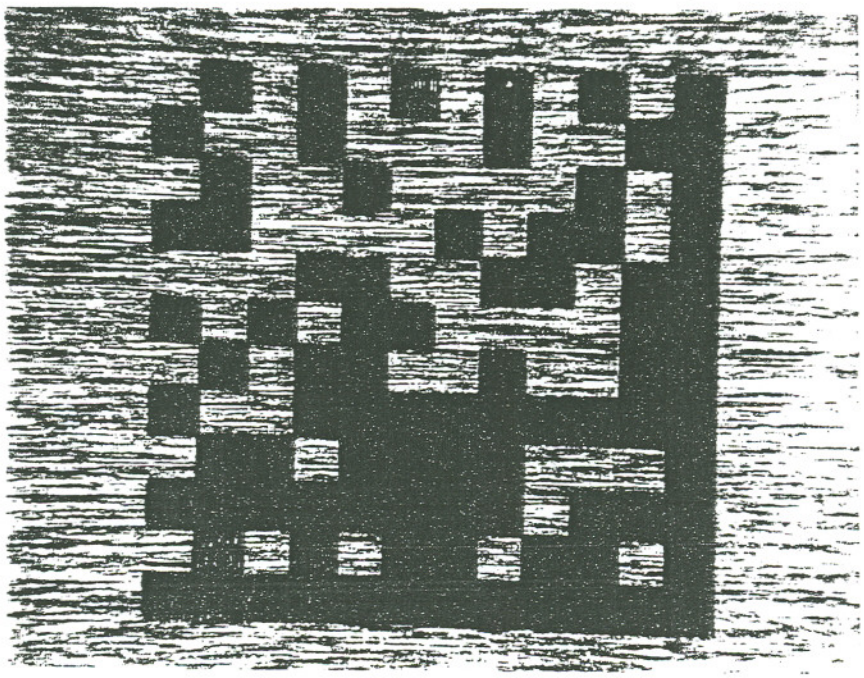


Fig. 4: Test 4, 17-4 PH, as received, 13x

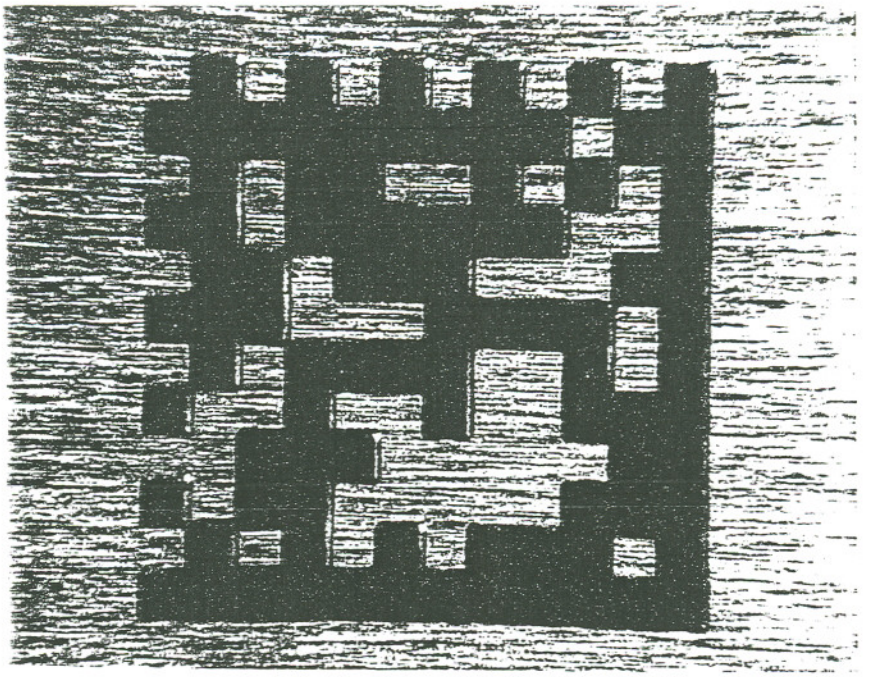


Fig. 5: Test 5, 17- 4 PH, as received. 13x

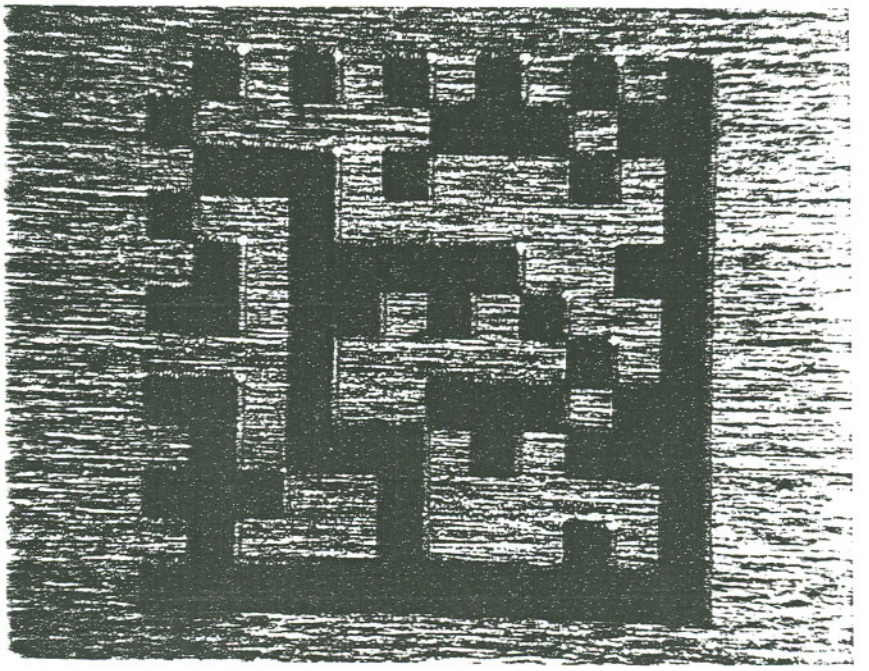


Fig. 6: Test 6, 17- 4 PH, as received. 13x

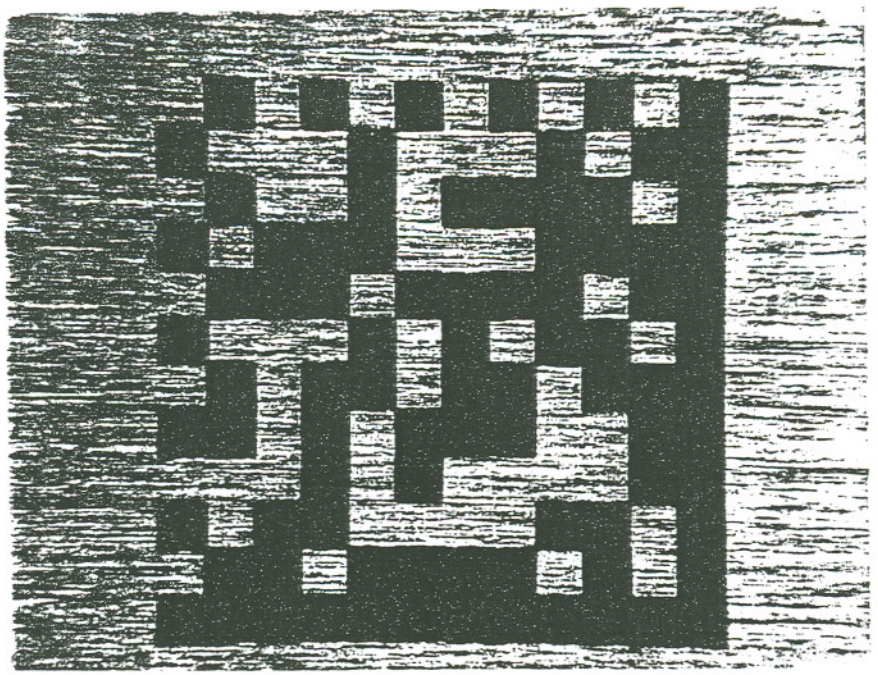


Fig. 7: Test 7, 17- 4 PH, as received. 13x

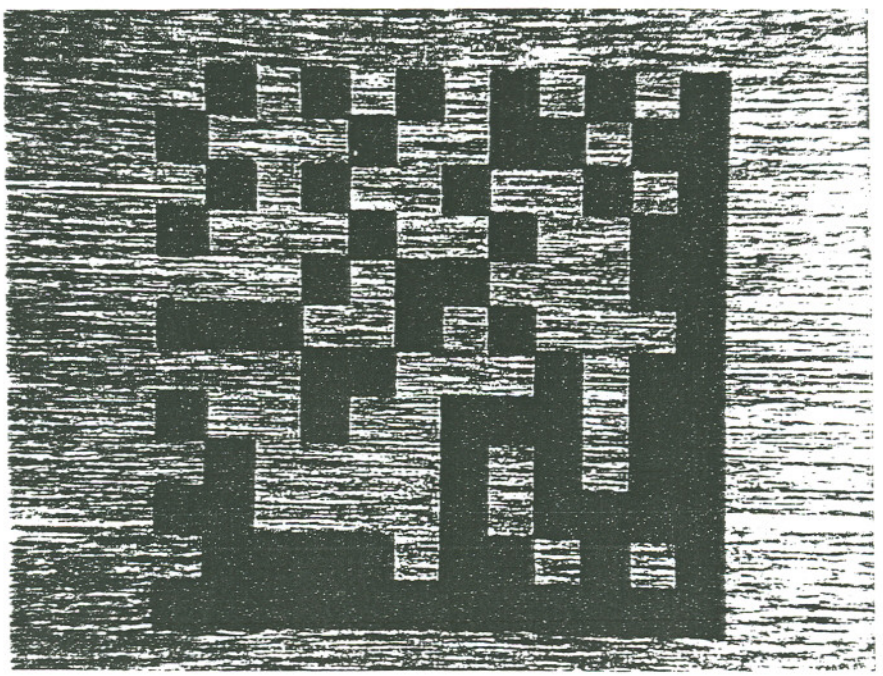


Fig. 8: Test 8, 17- 4 PH, as received. 13x

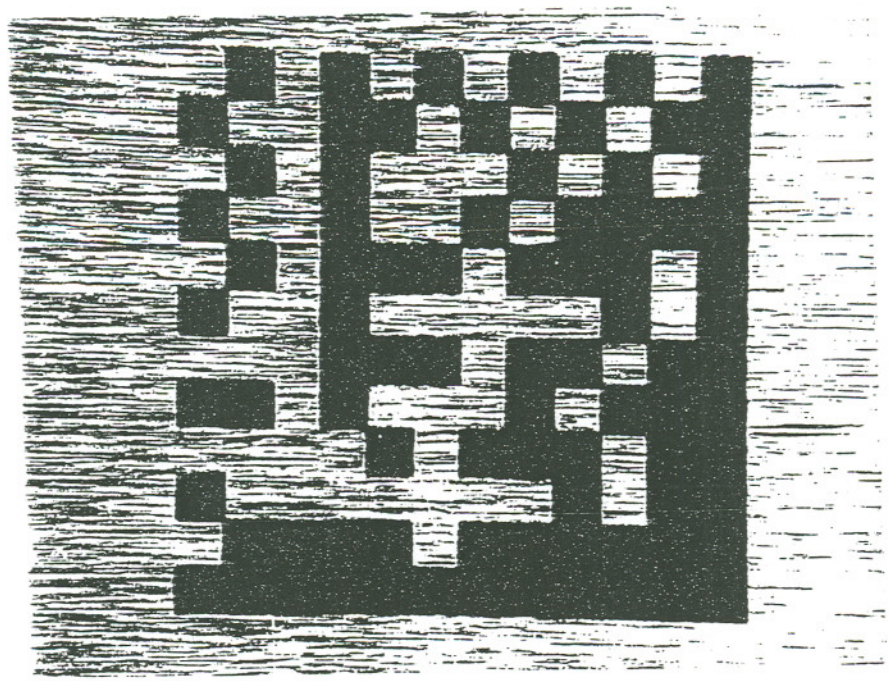


Fig. 9: Test 1, 4340 Steel, as received. 13x

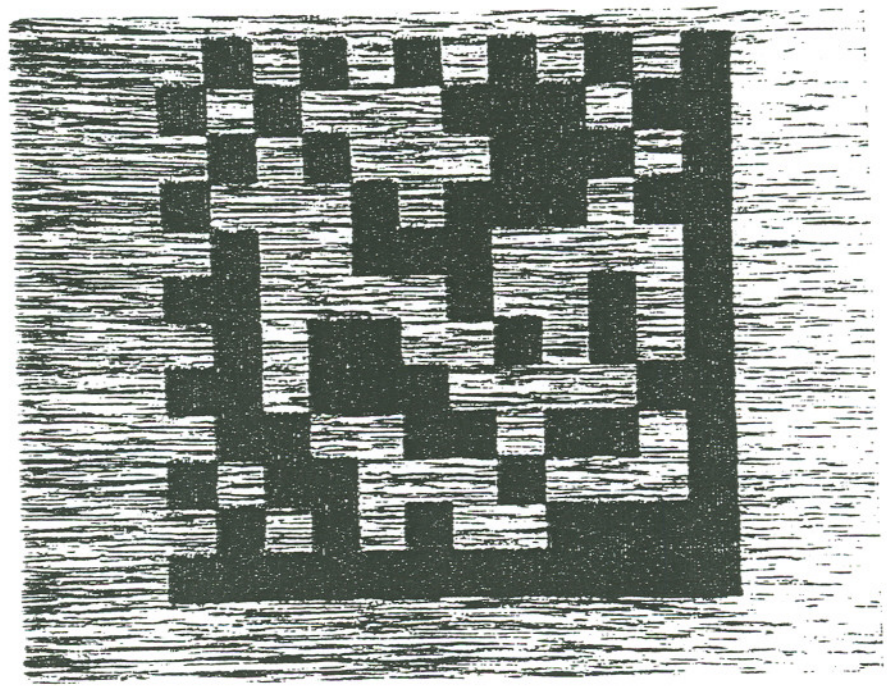


Fig. 10: Test 2, 4340 Steel, as received. 13x

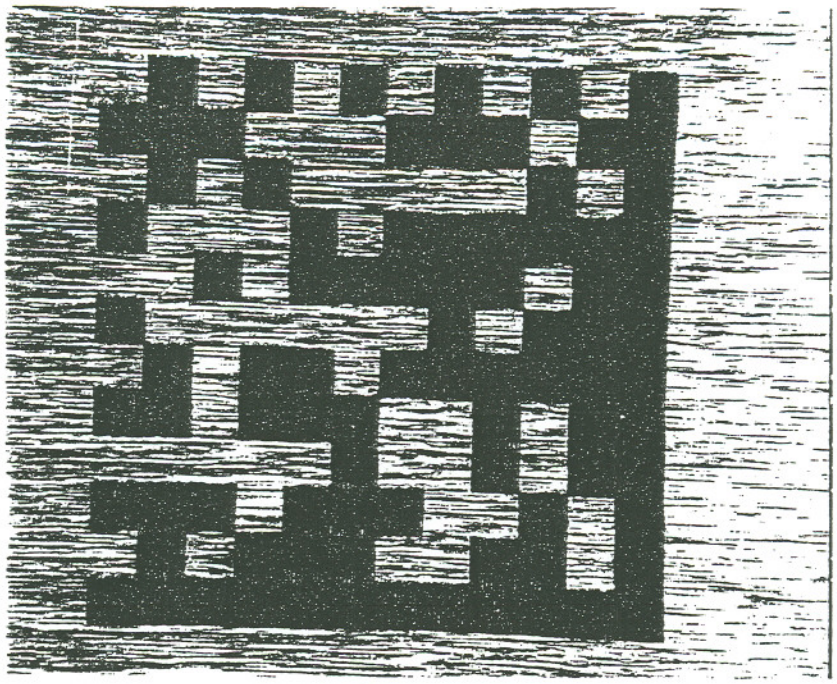


Fig. 11: Test 3, 4340 Steel, as received. 13x

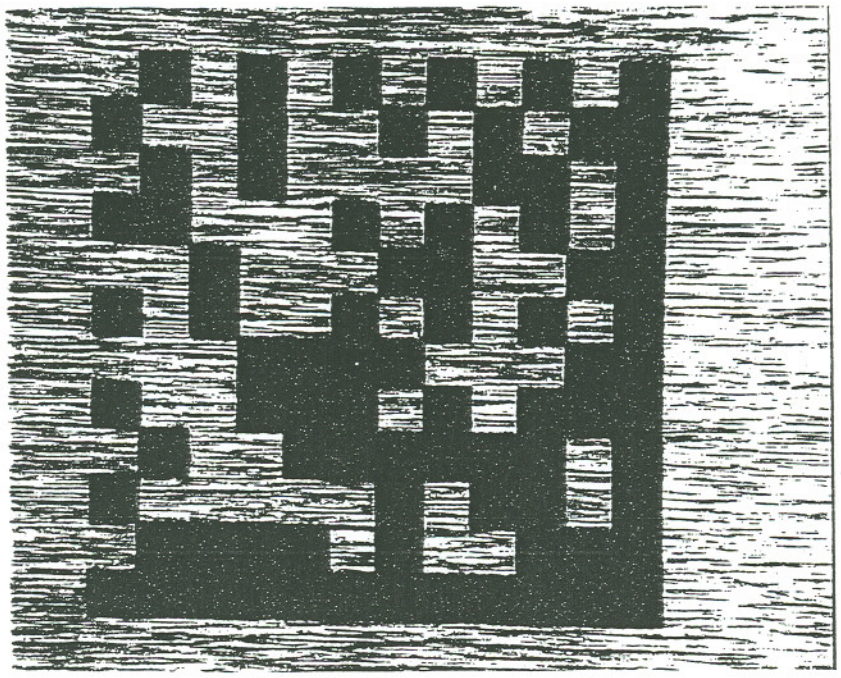


Fig. 12: Test 4, 4340 Steel, as received. 13x

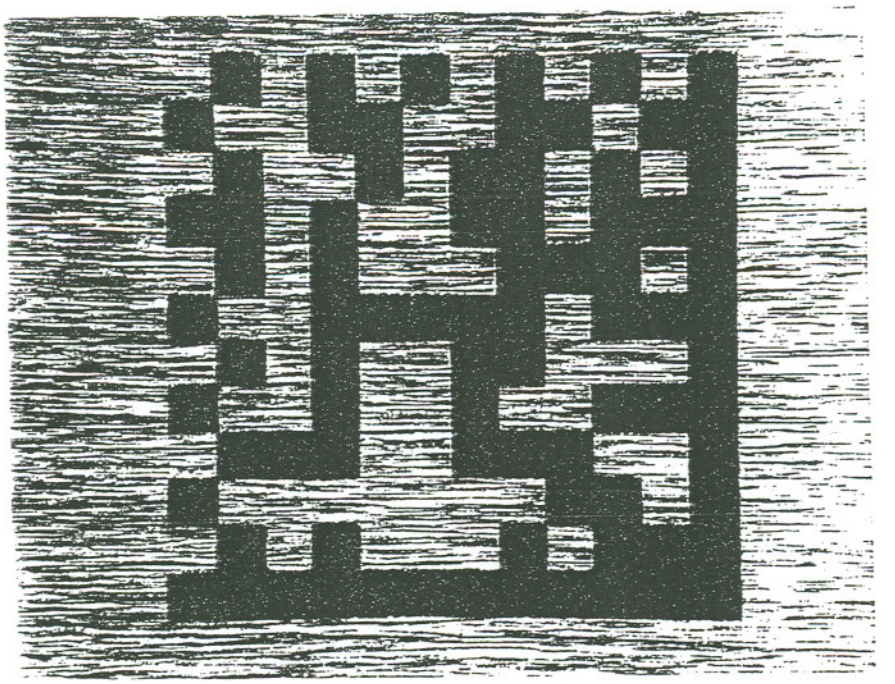


Fig. 13: Test 5, 4340 Steel, as received. 13x

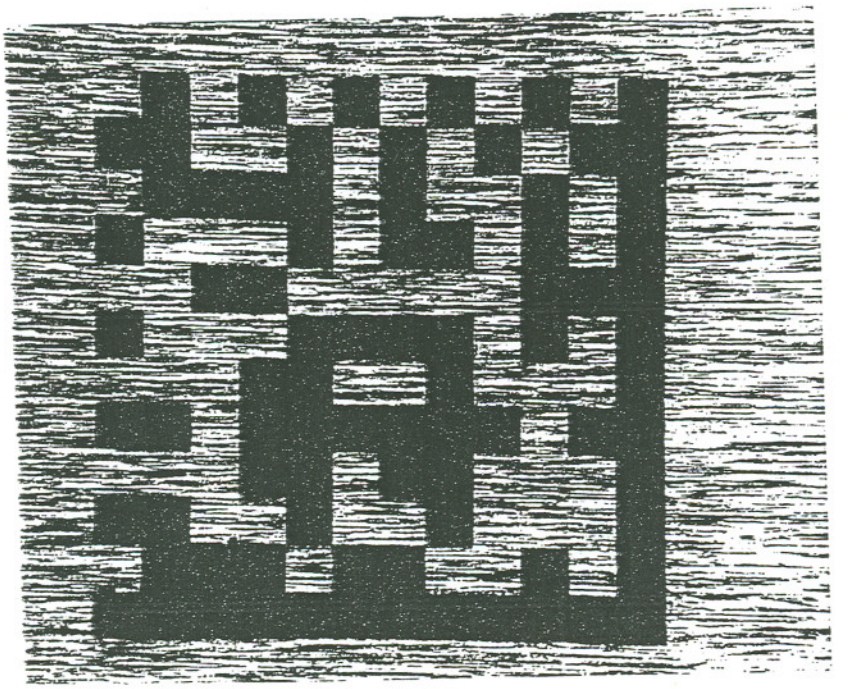


Fig. 14: Test 6, 4340 Steel, as received. 13x

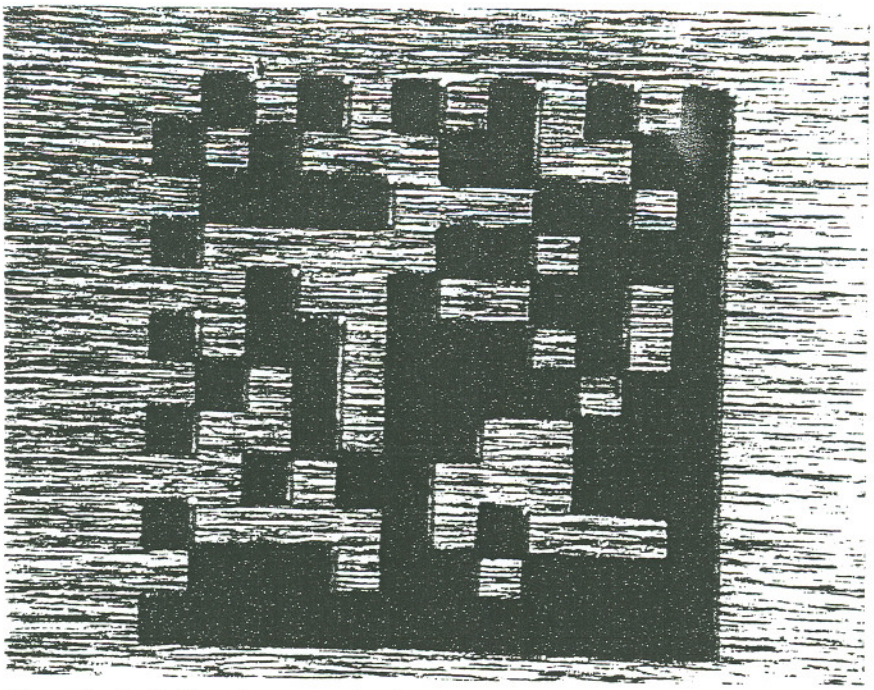


Fig. 15: Test 7, 4340 Steel, as received. 13x

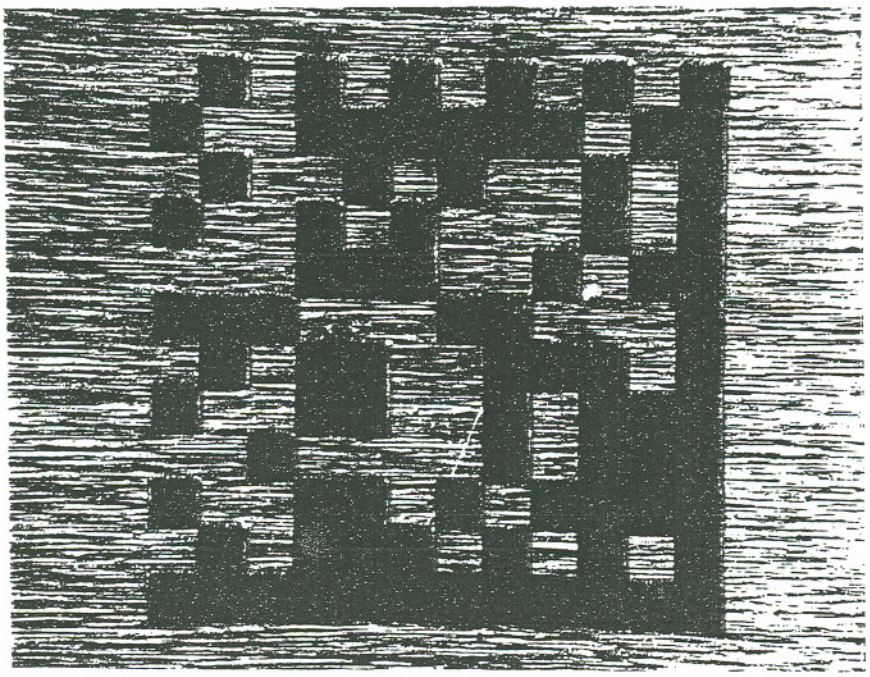


Fig. 16: Test 8, 4340 Steel, as received. 13x

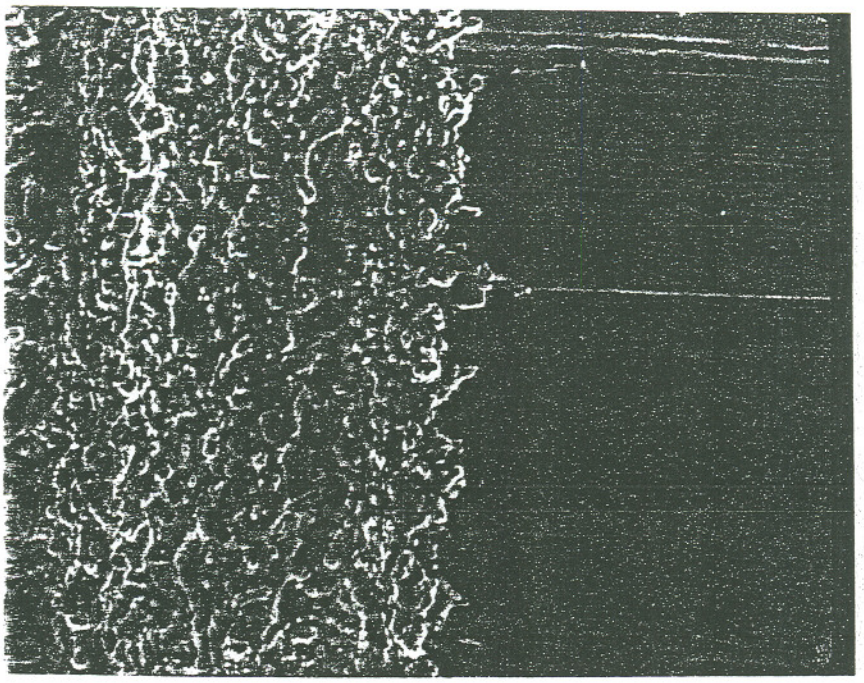


Fig. 17: Test 1, 17-4 PH, interface between laser mark and bare metal. 500x

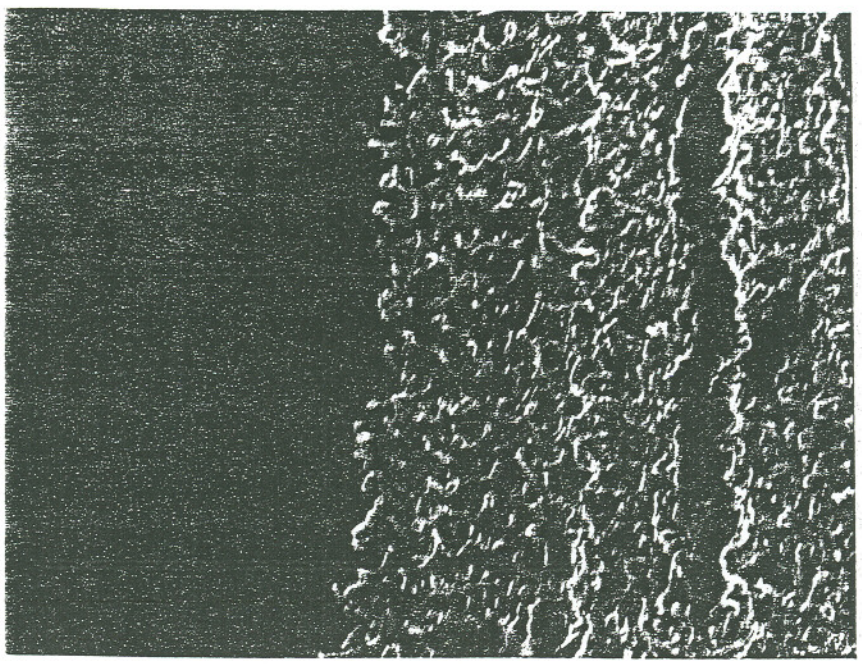


Fig. 18: Test 2, 17-4 PH, interface between laser mark and bare metal. 500x

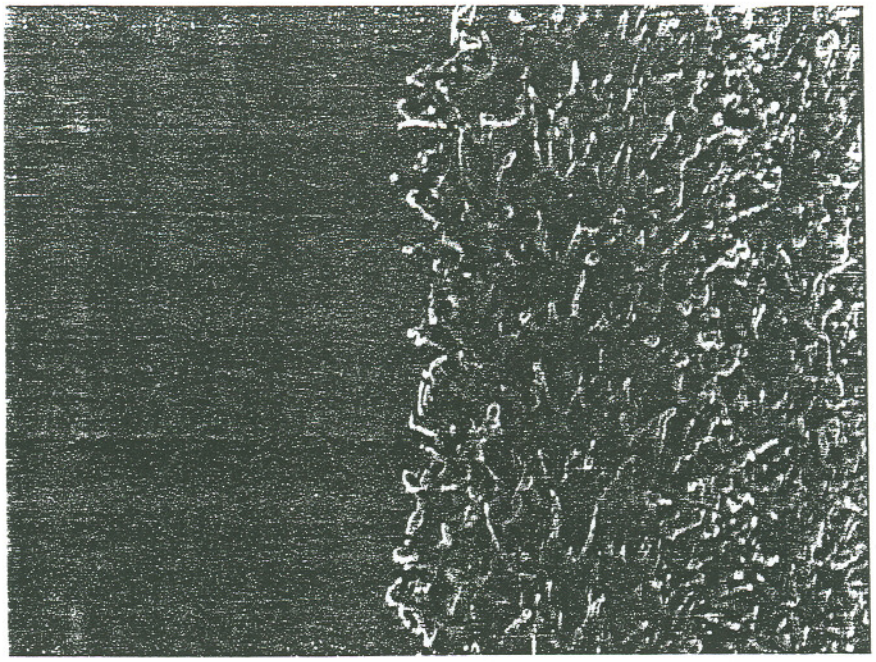


Fig. 19: Test 3, 17-4 PH, interface between laser mark and bare metal. 500x

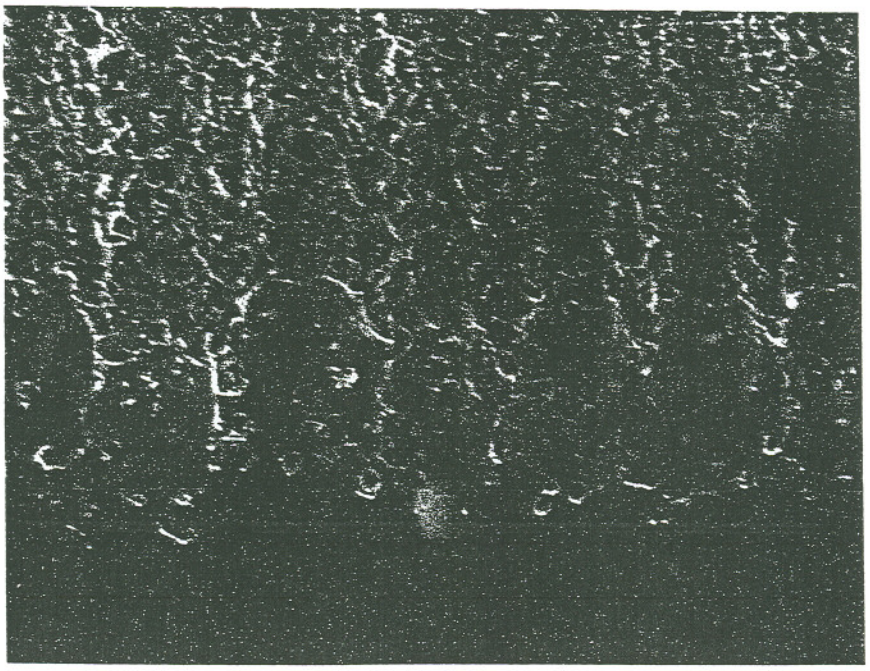


Fig. 20: Test 4, 17-4 PH, interface between laser mark and bare metal. 500x

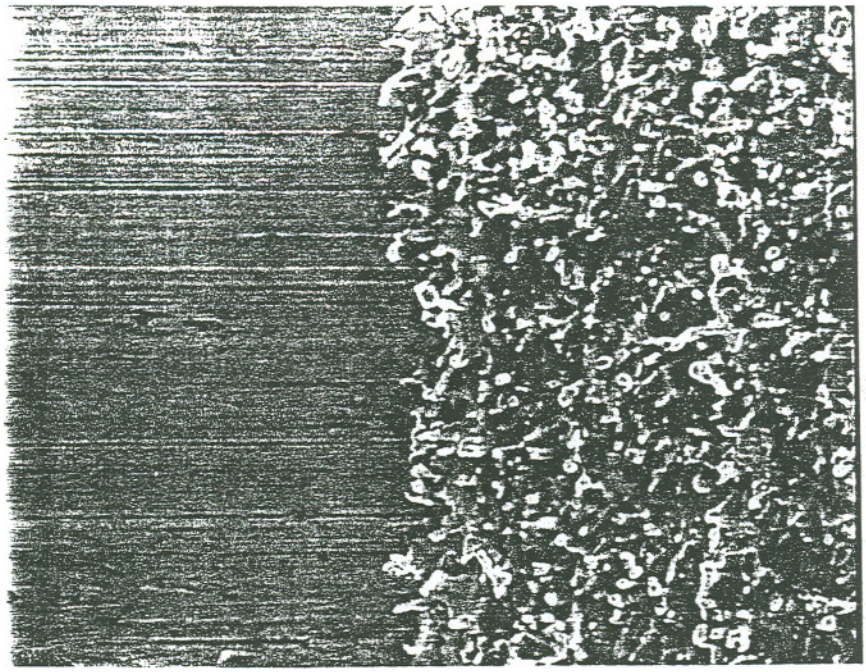


Fig. 21: Test 5, 17-4 PH, interface between laser mark and bare metal. 500x

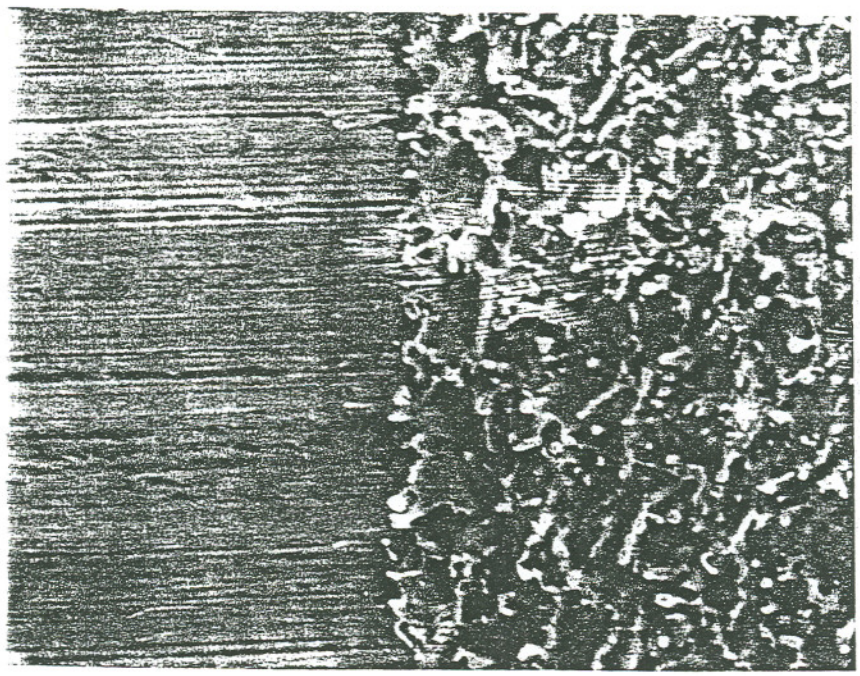


Fig. 22: Fig. Test 6, 17-4 PH, interface between laser mark and bare metal. 500x

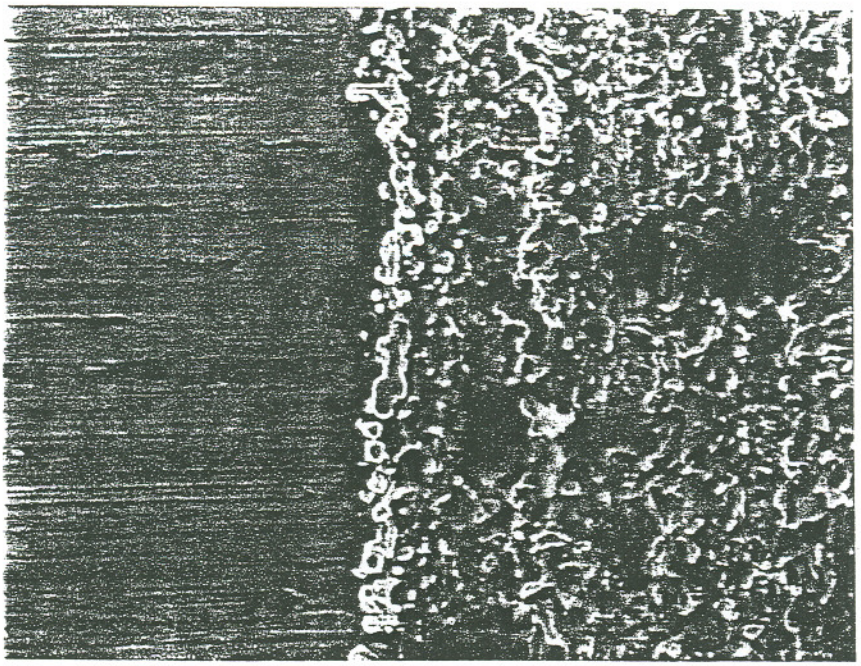


Fig. 23: Test 7, 17-4 PH, interface between laser mark and bare metal. 500x

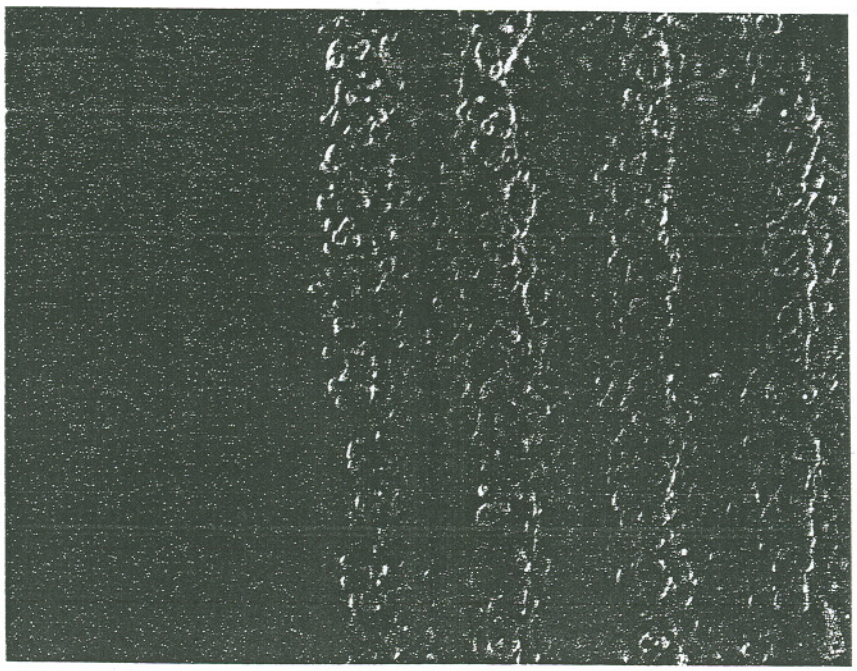


Fig. 24: Test 8, 17-4 PH, interface between laser mark and bare metal. 500x

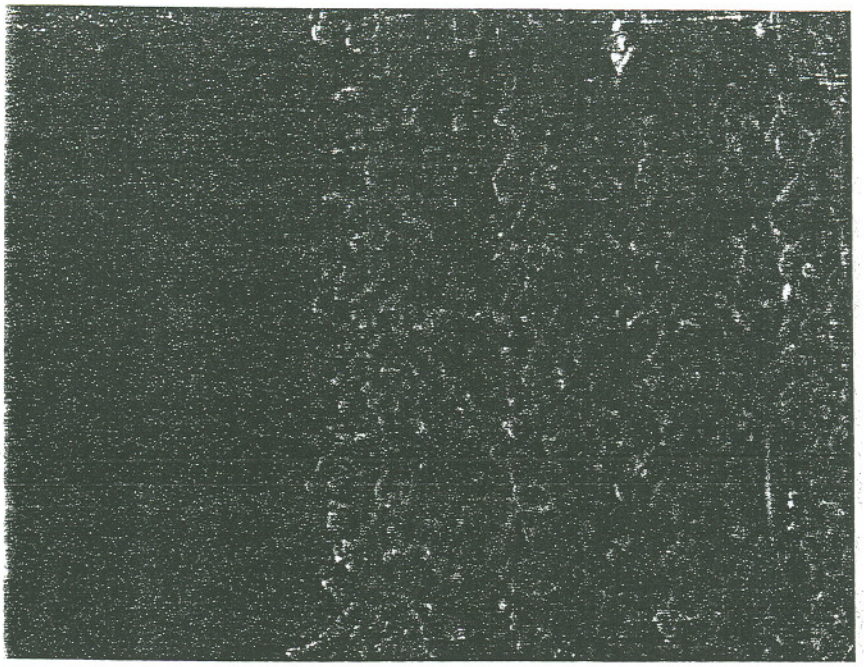


Fig. 25: Test 1, 4340 Steel, interface between laser mark and bare metal. 500x

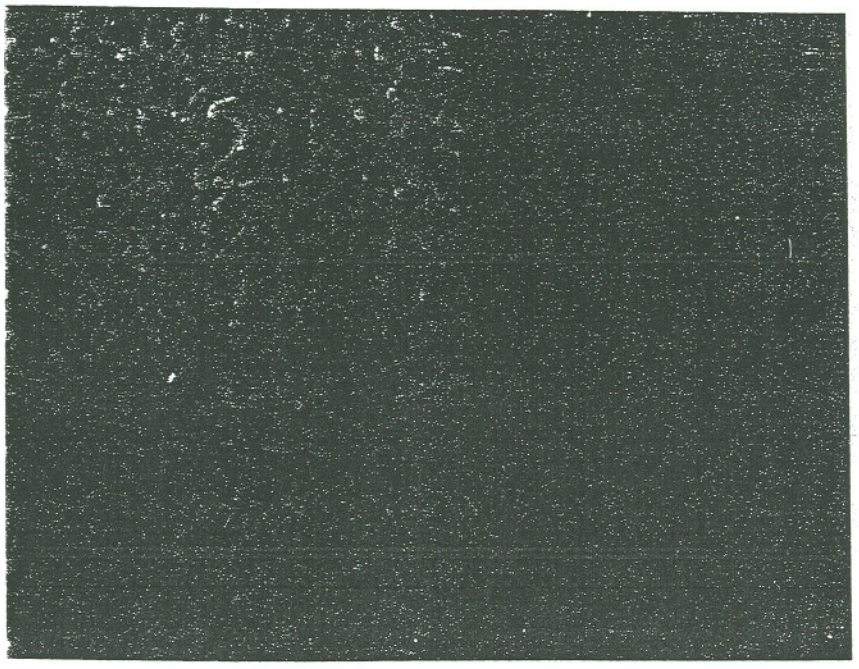


Fig. 26: Test 2, 4340 Steel, interface between laser mark and bare metal. 500x

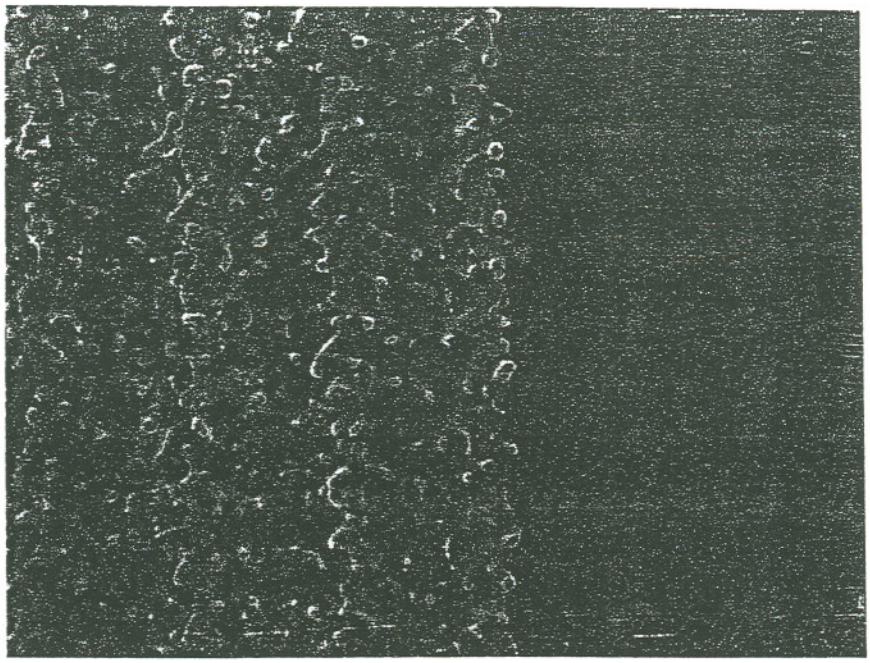


Fig. 27: Test 3, 4340 Steel, interface between laser mark and bare metal. 500x

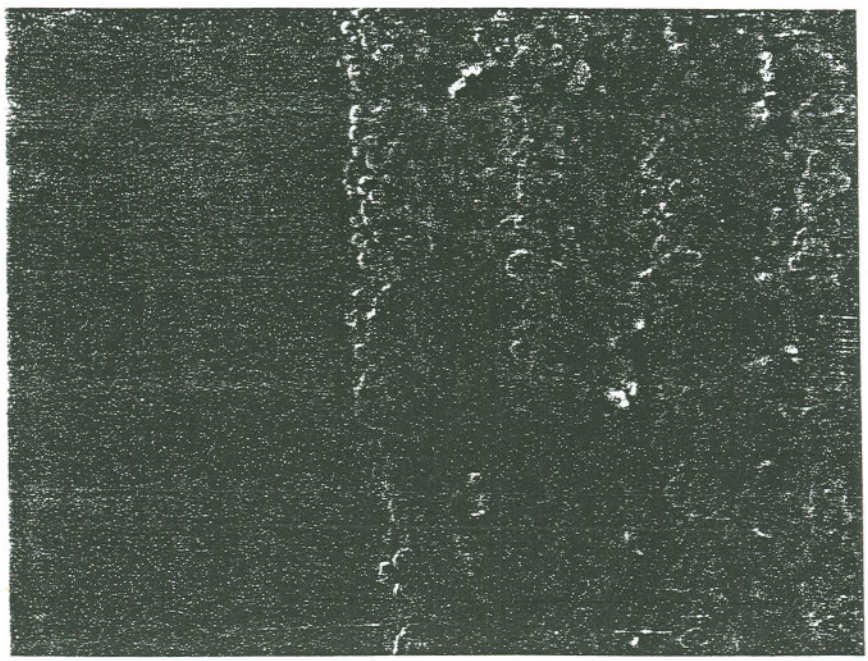


Fig. 28: Test 4, 4340 Steel, interface between laser mark and bare metal. 500x

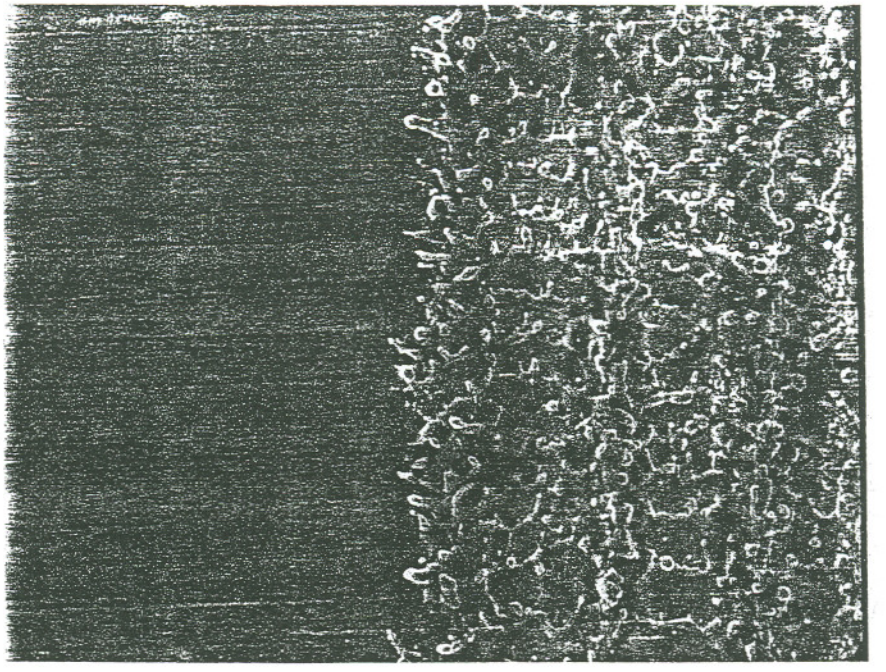


Fig. 29: Test 5, 4340 Steel, interface between laser mark and bare metal. 500x

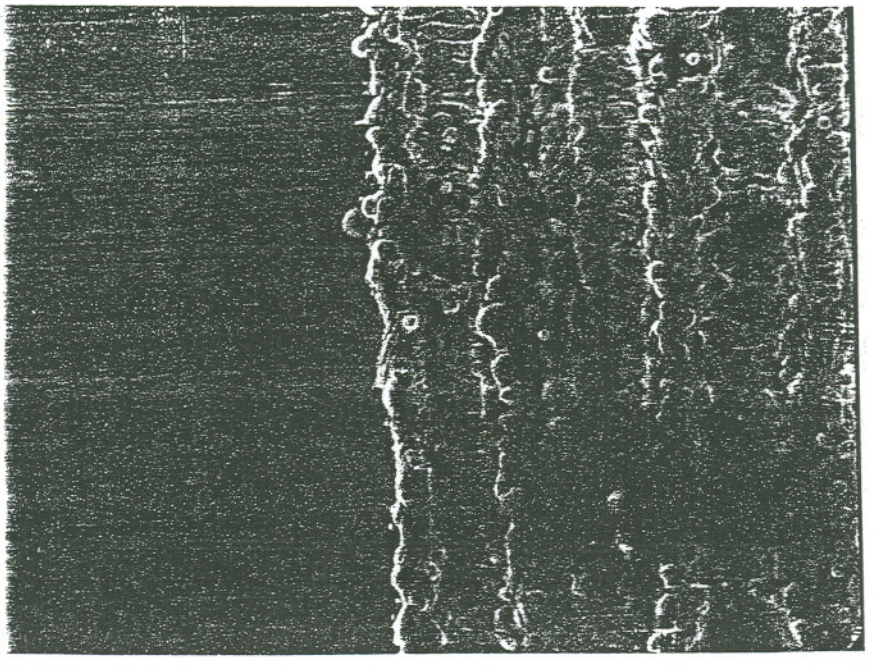


Fig. 30: Test 6, 4340 Steel, interface between laser mark and bare metal. 500x

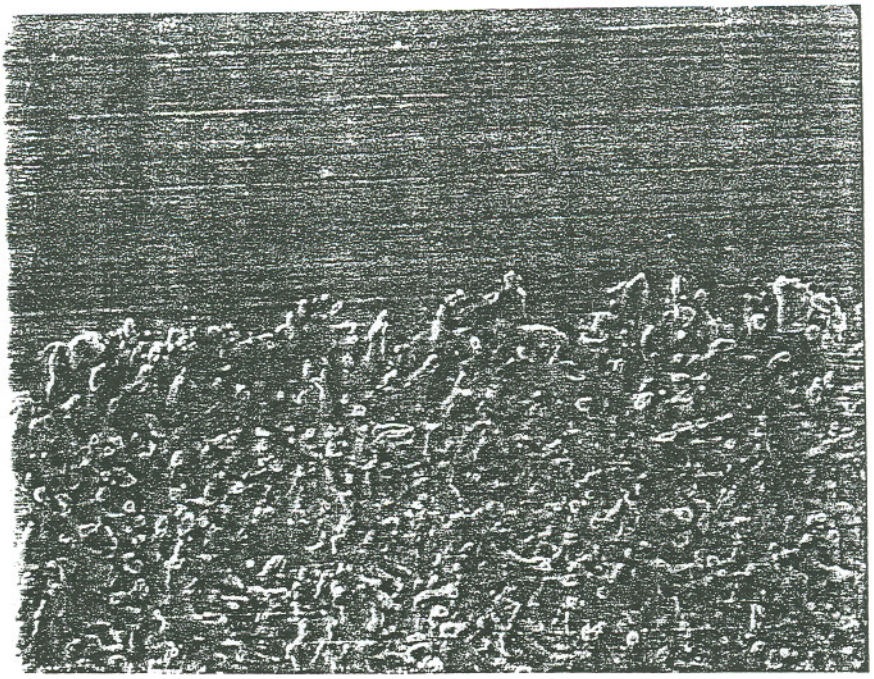


Fig. 31: Test 7, 4340 Steel, interface between laser mark and bare metal. 500x

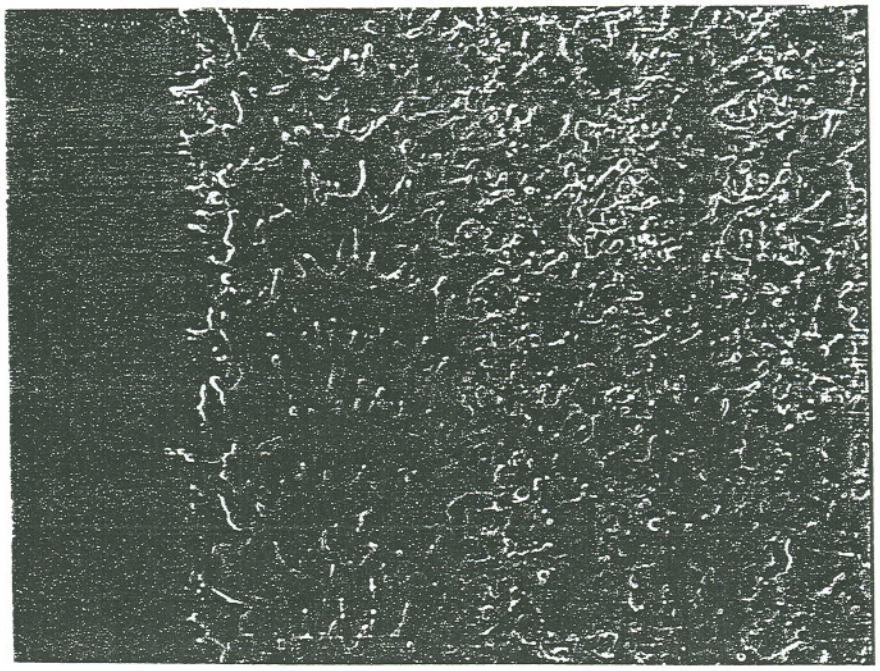


Fig. 32: Test 8, 4340 Steel, interface between laser mark and bare metal. 500x

Fig. 33: Test 1, 17-4 PH, cross section of laser mark. 100x

Fig. 34: Test 2, 17-4 PH, cross section of laser mark. 100x

Fig. 35: Test 3, 17-4 PH, cross section of laser mark. 100x

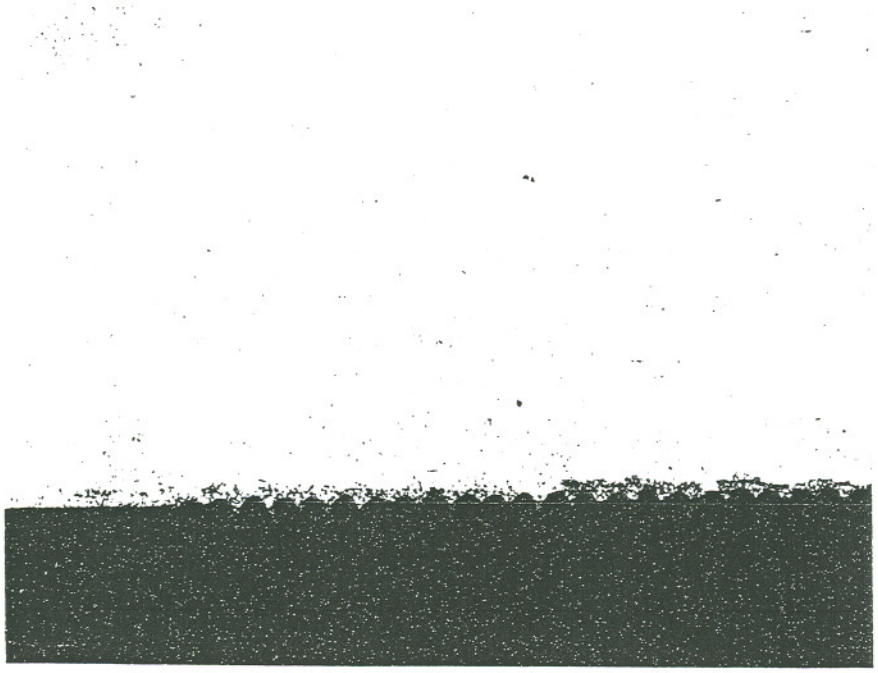


Fig. 36: Test 4, 17-4 PH, cross section of laser mark. 100x

Fig. 37: Test 5, 17-4 PH, cross section of laser mark. 100x

Fig. 38: Test 6, 17-4 PH, cross section of laser mark. 100x

Fig. 39: Test 7, 17-4 PH, cross section of laser mark. 100x

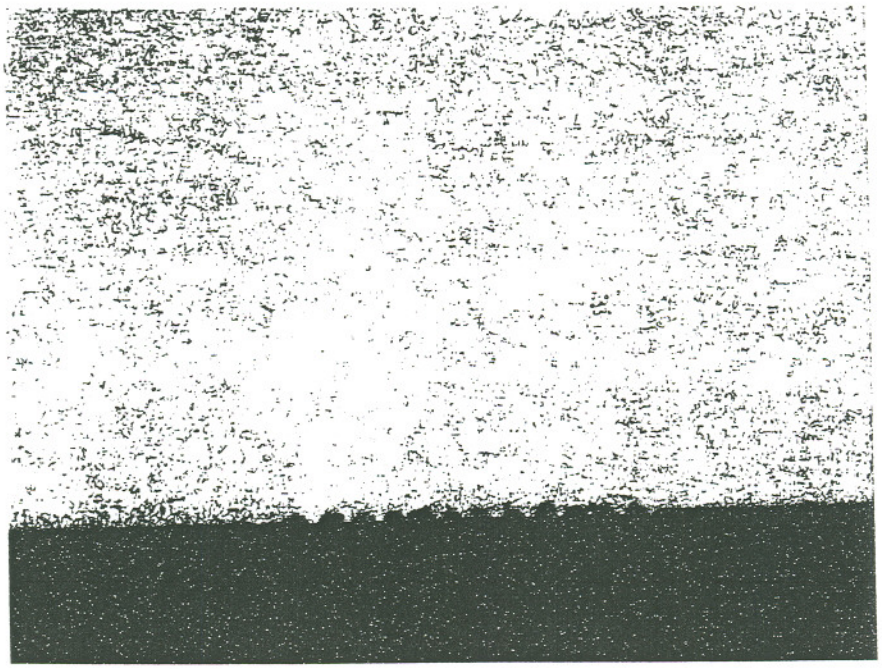


Fig. 40: Test 8, 17-4 PH, cross section of laser mark. 100x

Fig. 45: Test 5, 4340 Steel, cross section of laser mark. 100x

Fig. 46: Test 6, 4340 Steel, cross section of laser mark. 100x

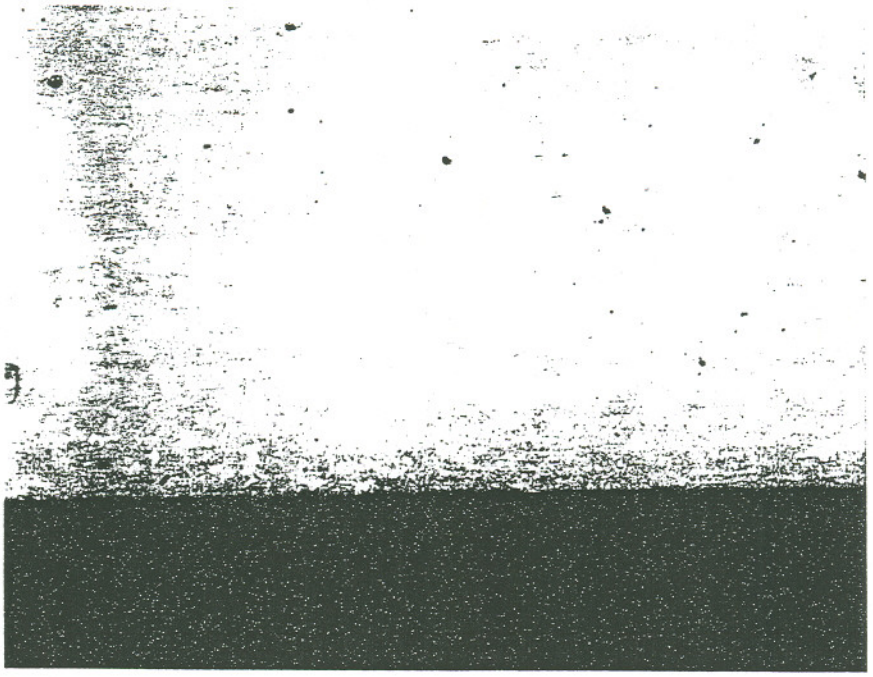


Fig. 47: Test 7, 4340 Steel, cross section of laser mark. 100x

Fig. 48: Test 8, 4340 Steel, cross section of laser mark. 100x

Fig. 41: Test 1, 4340 Steel, cross section of laser mark. 100x

Fig. 42: Test 2, 4340 Steel, cross section of laser mark. 100x

Fig. 43: Test 3, 4340 Steel, cross section of laser mark. 100x

Fig. 44: Test 4, 4340 Steel, cross section of laser mark. 100x

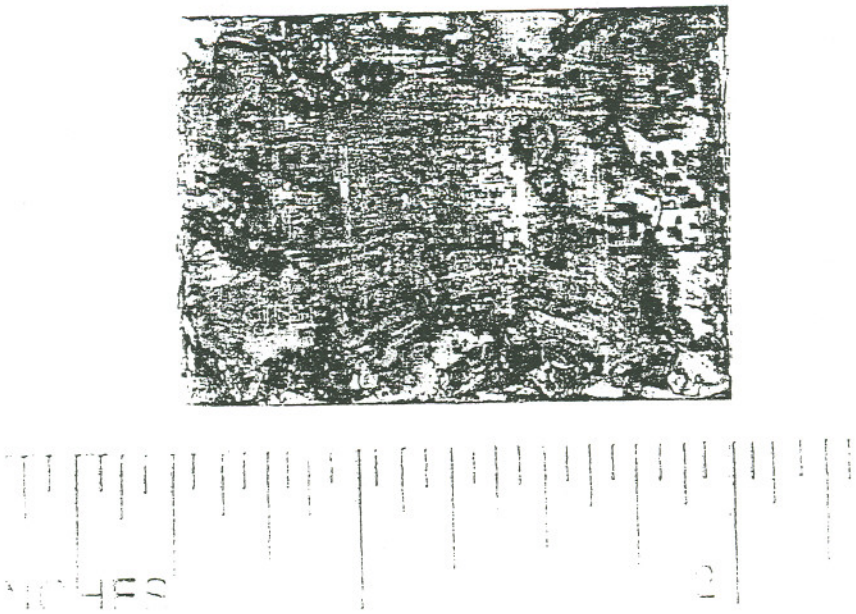


Fig. 49: 4340 Steel with laser marks after approx. 1 week in salt fog.

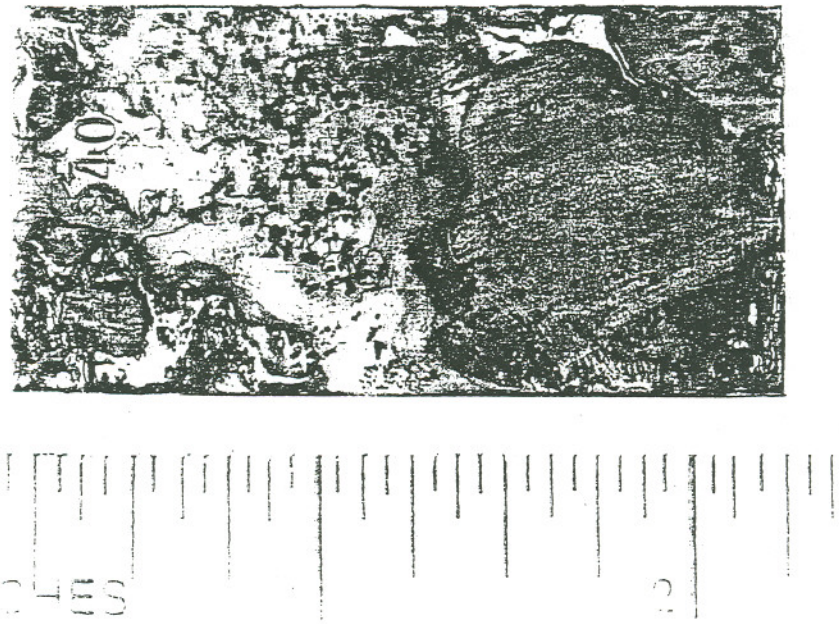


Fig. 50: 4340 steel control (no laser marks) after approx. 1 week in salt fog.

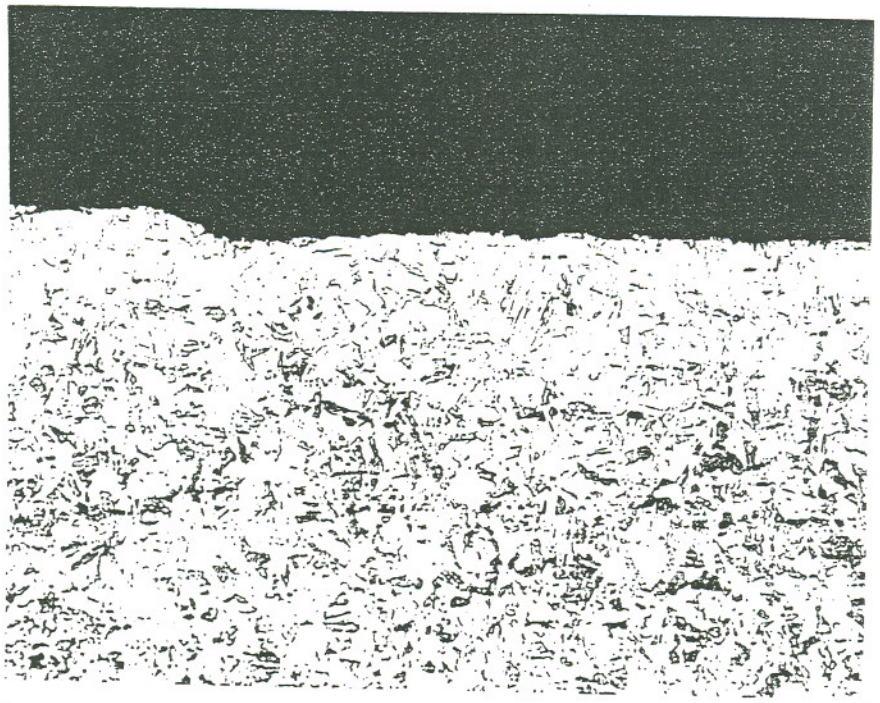


Fig. 51: Cross section of 17-4 PH laser marked coupon following approx. 1 month of salt fog. 400x

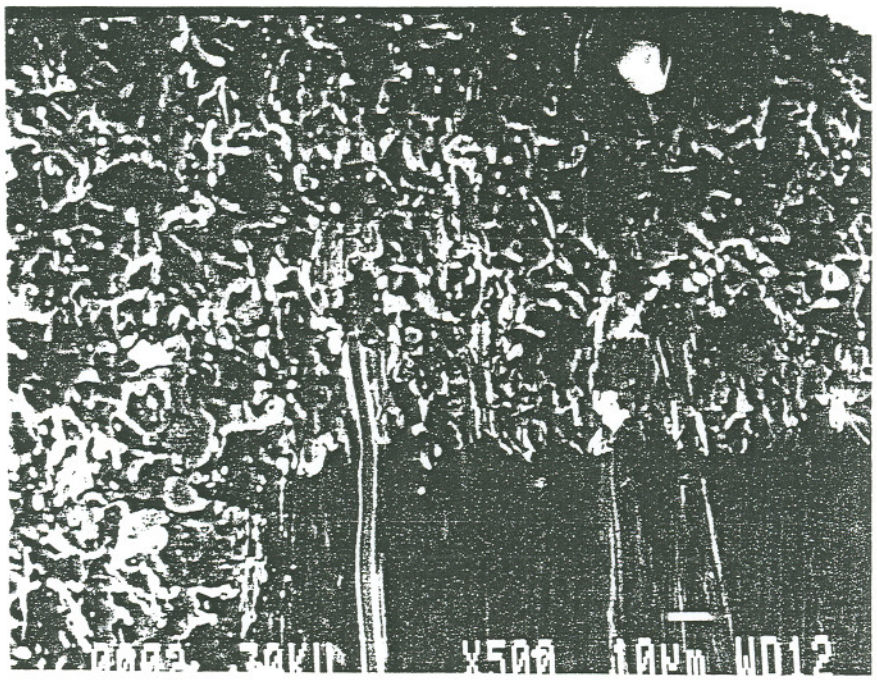
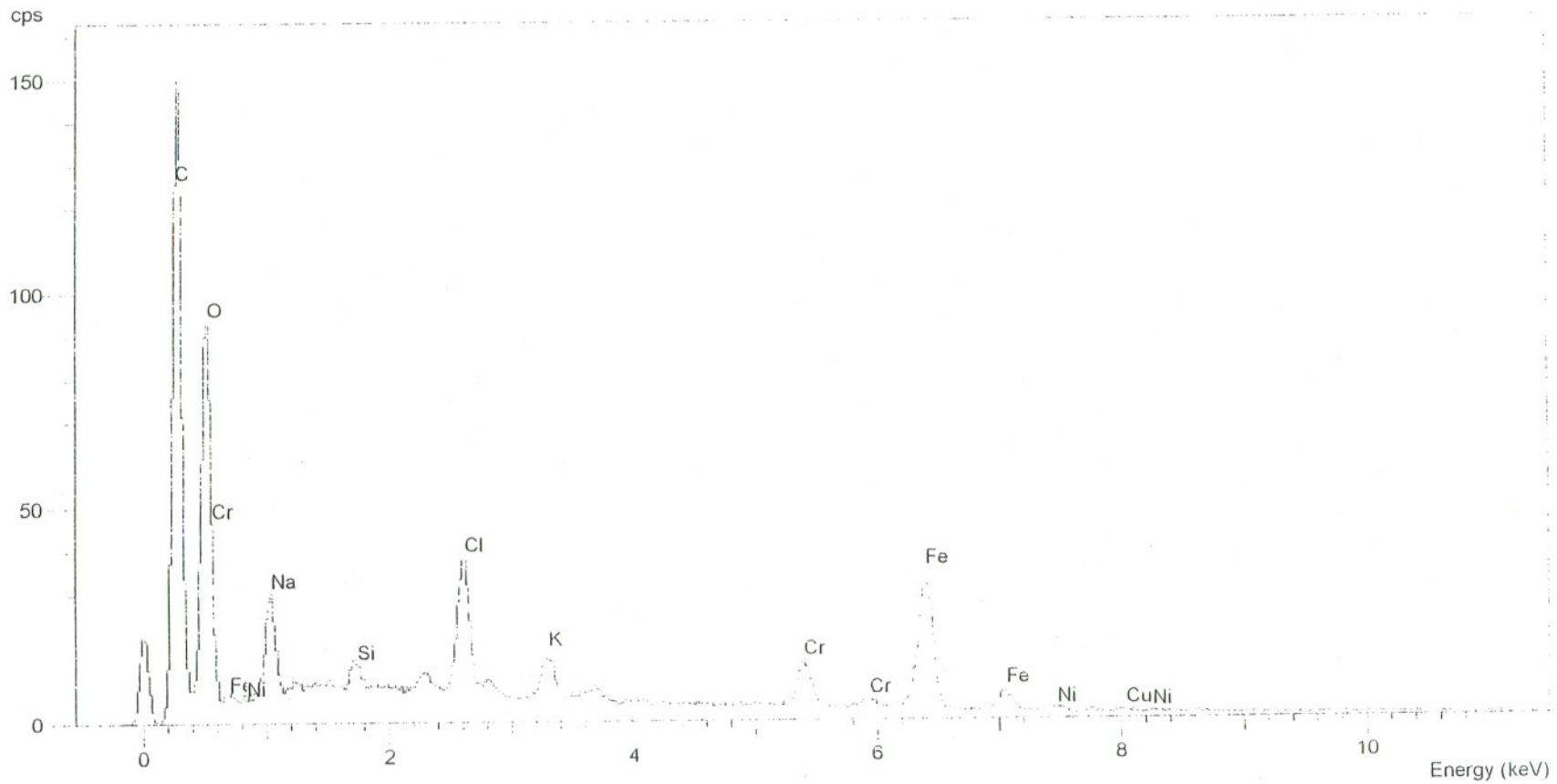


Fig. 52: Interface between laser mark and bare metal of 17-4 PH following approx. 1 month of salt fog. 500x

Fig. 53: EDS spectrum of typical corrosion products on surface of 17-4 PH coupon following approx. 1 month of salt fog.



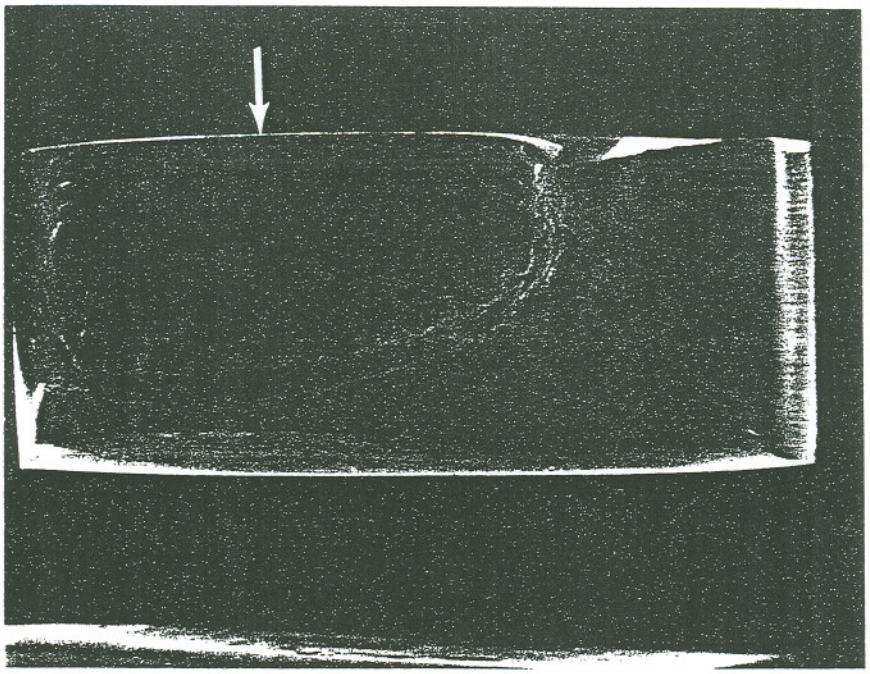


Fig. 54: Fracture face of fatigue specimen 66.5-2. Arrow shows initiation site. 16x

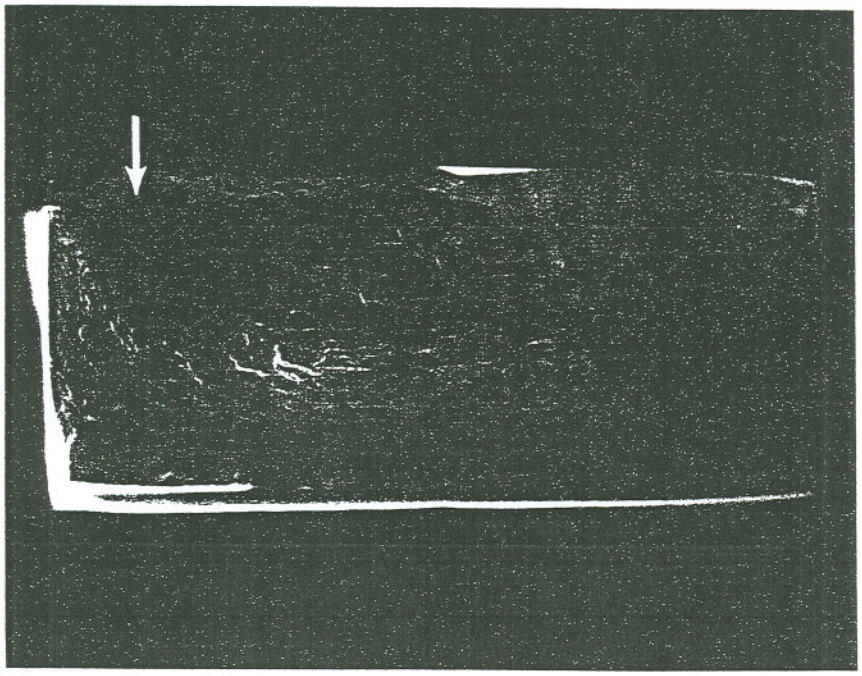


Fig. 55: Fracture face of fatigue specimen 70-1. Arrow shows initiation site at non-metallic inclusion. 16x

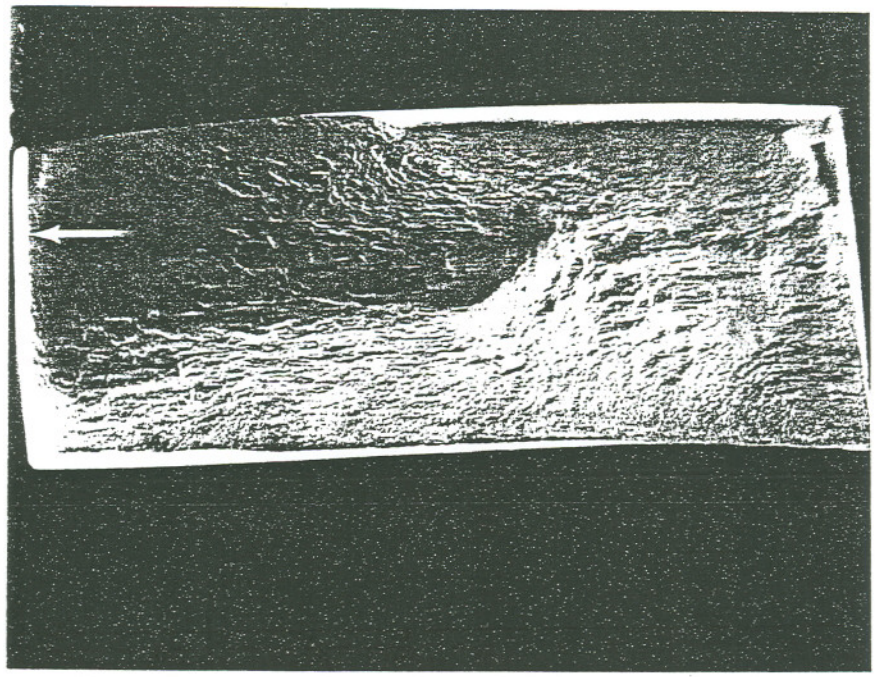


Fig. 56: Fracture face of fatigue specimen 75-3. Arrow shows initiation site. 16x

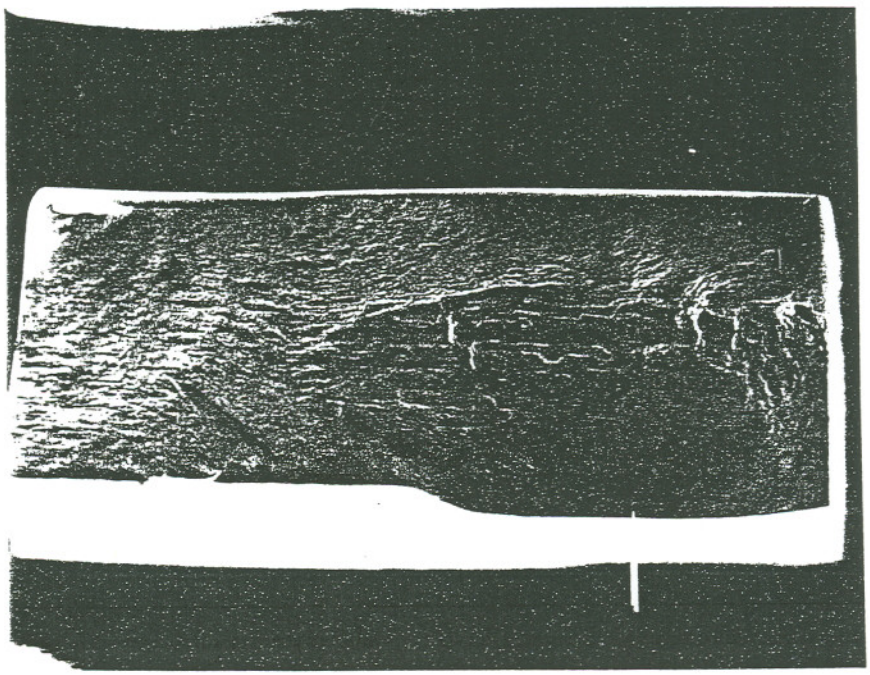
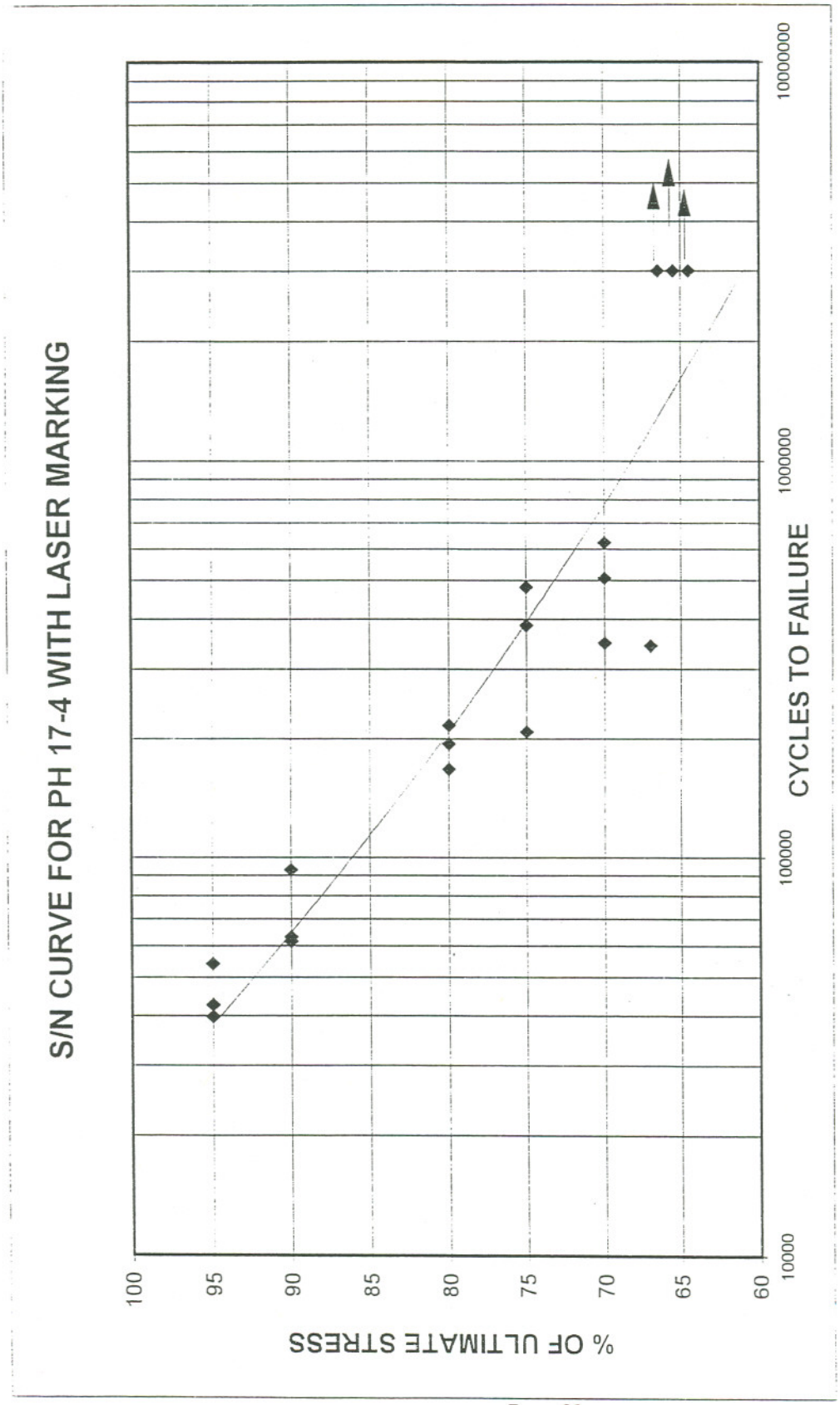


Fig. 57: Fracture face of fatigue specimen 80-3. Arrow shows initiation site. 16x

Fig. 58: Revised S/N curve for laser marked 17-4 PH, condition A.



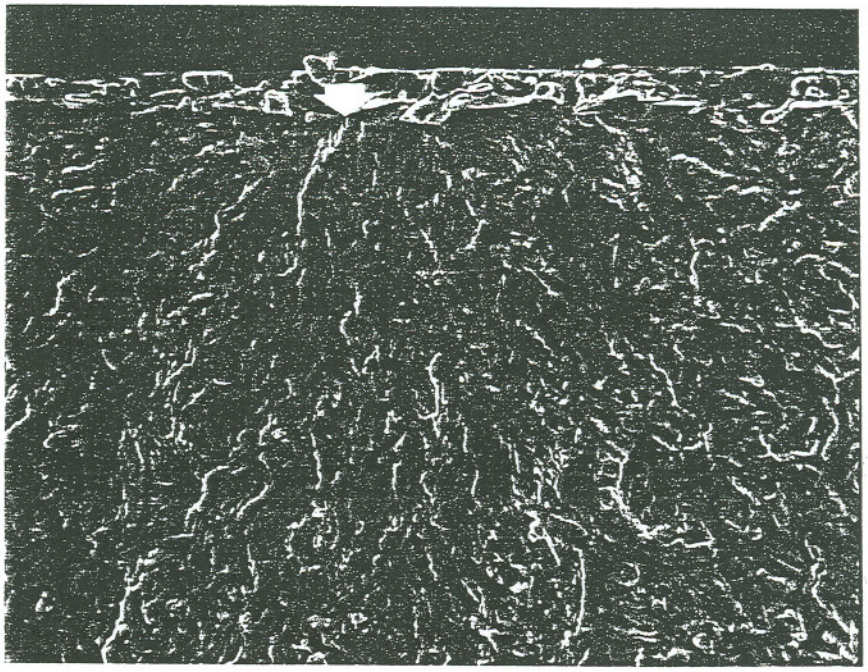


Fig. 59: Fatigue initiation site for coupon 66.5-2, arrow. 1000x

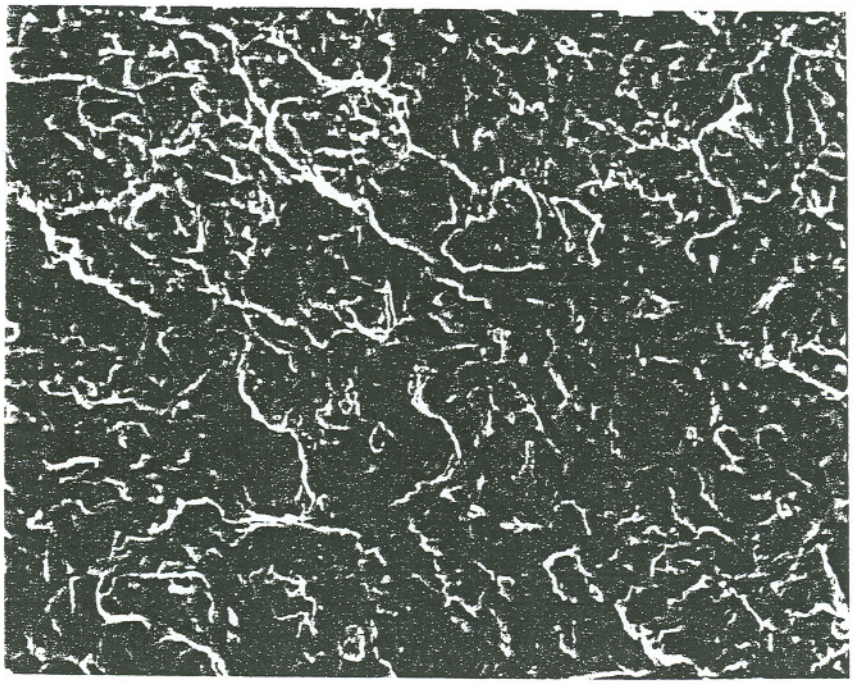


Fig. 60: Typical fracture morphology in fatigue zone. Crack propagated from lower right to upper left. 1000x

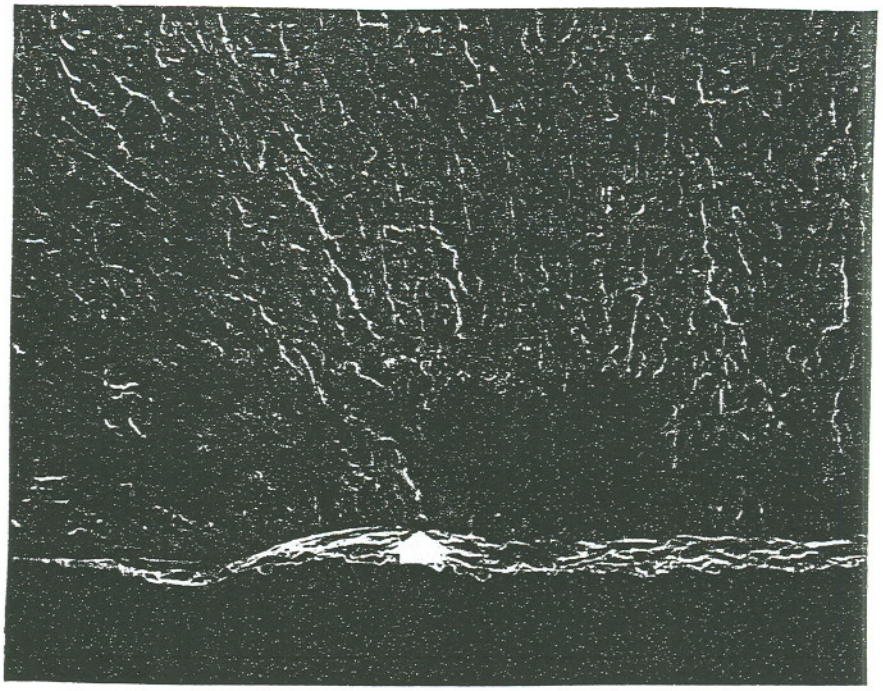


Fig. 61: Initiation site of a typical coupon (95-2) that failed at a laser mark. 500x

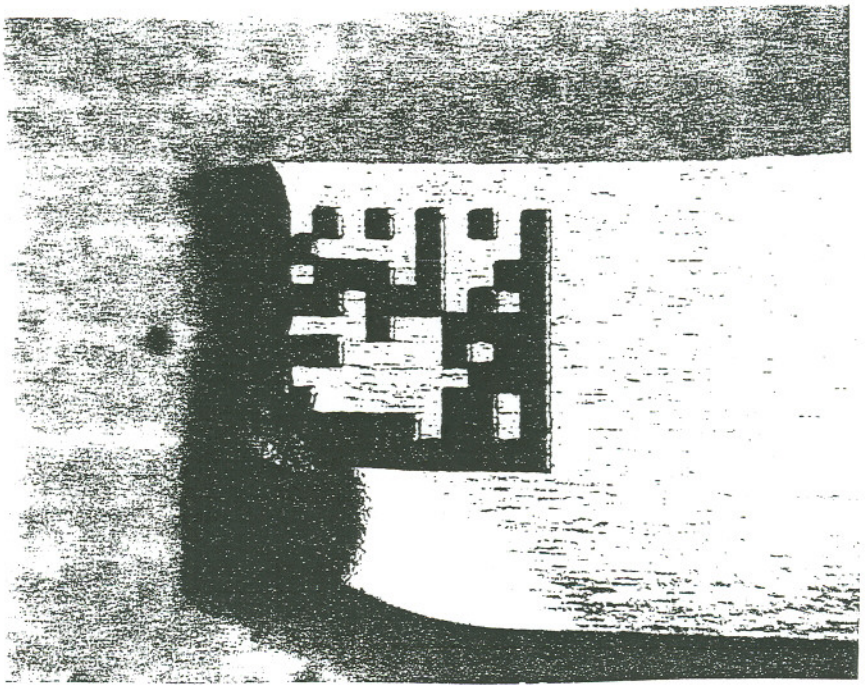
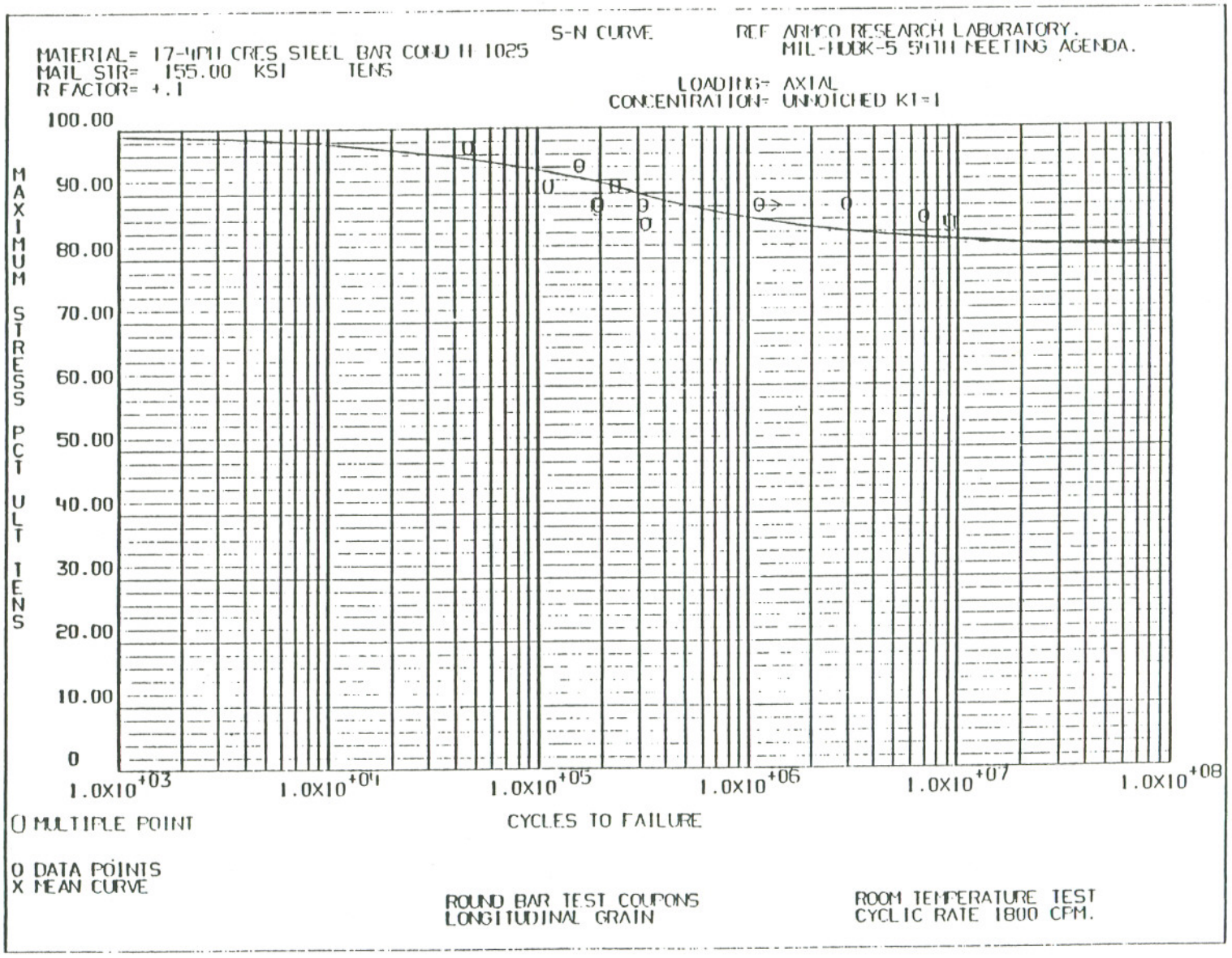


Fig. 62: Relative location on the laser mark where most specimens failed. 10x



LOS ANGELES DIVISION
ROCKWELL CORPORATION.
BY J.STOLPESTAD
CHKR
FATIGUE DESIGN PROPERTIES MANUAL
NA-72-1088
MARCH 1979

17-4PH STEEL BAR H-1025

Fig. 63: S/N curve for comparison

APPENDIX C: REPORT 400-2619, HIGH CYCLE FATIGUE TESTING OF LASER MARKED TEST SPECIMENS

Boeing North American

M&P Laboratories
Test Report

Number 400-2619

Date Rec'd 3/18/98

Nomenclature/Subject High Cycle Fatigue Testing of Laser Marked Test Specimens

Contract/LR 7183 Specification ASTM E-466

Requester T. Wittman Dept. 284 Location Downey Phone 562-922-0191

Laboratory Notebook Pages N/A

Introduction

BNA - Reuseable Space Systems (RSS), Huntsville, has been contracted by the United States Coast Guard (USCG) to conduct a pilot program to demonstrate the feasibility of using a two-dimensional (2-D) matrix symbology-based automated parts identification (API) system for marking and tracking flight critical parts.

The laser marked symbols were produced at the BNA-Huntsville 2-D Symbology Center with a Landmark Laser Marking System, model LBI-6000. The marked coupons were evaluated for readability at BNA-Huntsville, then sent to Downey for metallurgical evaluation. Following this initial evaluation, the optimal set of parameters was selected and more coupons were produced. The second phase consisted of salt spray testing and the coupons were again evaluated for readability and metallurgical soundness. This test report addresses the final phase of the metallurgical evaluation, the high cycle fatigue testing to determine if the laser markings had a detrimental effect on fatigue properties.

Samples

17-4 PH stainless steel Cond. A. material was supplied by Armco Advanced Materials Co. of Butler Pa. This material was sent to Metal Samples Co. of Munford Al., who manufactured 24 fatigue test specimens per L & T Std. Dwg. 0031. The laser marking procedure described above was performed on 21 of the 24 samples. The remaining three specimens were set aside as control samples. The laser code marking was located at the middle of the test specimen, where cross sectional area is at a minimum. All 24 specimens were delivered to the M & P lab for fatigue testing. Test specimens were measured and identified prior to testing.

Test Setup

Test specimens were fatigue tested per ASTM E-466 in a MTS Servo Hydraulic load frame interfaced to a MTS 442 Controller. The flat specimens were held with wedge type hydraulic grips.

Test Procedure

Before fatigue testing was initiated, two unmarked control samples were pulled to failure in order to determine the ultimate strength of the 17-4 material. The average ultimate strength of the two samples was 164.8 Ksi. All fatigue loads were based on percentages of this value.

The 21 laser marked test specimens were fatigue tested at R = 0.1 at a frequency of 30 Hz. Fatigue runout was established at 3 million cycles. Fatigue tests were conducted at the following load levels: 95%, 90%, 80%, 75%, 70%, and 66.5% of ultimate stress.

Results

All fatigue test data is shown in Table I and the Corresponding S/N curve is shown in Figure 1. Failure was expected to always occur in the laser marked region since it coincided with the location of minimum cross sectional area. However, four of the specimens failed outside the laser marked region. This phenomenon is not totally unexpected since edge effects of rectangular samples can induce stress concentrations and crack initiation. These four specimens are noted in the table.

When generating fatigue test data, some data scatter is expected. However, two specimens failed at a significantly lower cycle count values than the other three specimens tested in the same load range (see specimen 80-2 and 66.5-2). Again, these anomalies may be due to edge effects, and are probably not related to the laser markings.

Summary

Test samples of laser marked 17-4 corrosion resistant steel were fatigue tested at R = 0.1 in the M & P lab. Twenty-one specimens were fatigue tested, and a S/N curve was generated. Test results will be reviewed by BNA - Reuseable Space Systems (RSS), Huntsville and the United States Coast Guard in a metallurgical evaluation to determine if laser markings have a detrimental effect on fatigue properties

Signed: Joel Slenk Date: 3/19/98

Approved: [signature] Date: 3-19-98

Table 1 Fatigue Test Data

Specimen #	Thick (in.)	Width (in.)	Area (in.^{2})	Percent F_{tu}	Max. Stress (ksi)	Min. Stress (ksi)	Max. Load (lb.)	Min. Load (lb.)	Frequency Hz.	Cycles to Failure
ULT-1	0.111	0.249	0.0276		164.98		4560			1
ULT-2	0.111	0.249	0.0276		164.62		4550			1
AVERAGE					**164.80**					
95-1	0.111	0.249	0.0276	95	156.56	15.66	4327	433	30	53,970
95-2	0.111	0.249	0.0276	95	156.56	15.66	4327	433	30	42,570
95-3	0.111	0.249	0.0276	95	156.56	15.66	4327	433	30	39,710
90-1	0.111	0.249	0.0276	90	148.32	14.83	4099	410	30	92,780
90-2	0.111	0.249	0.0276	90	148.32	14.83	4099	410	30	61,500
90-3	0.111	0.249	0.0276	90	148.32	14.83	4099	410	30	62,910
80-1	0.111	0.250	0.0278	80	131.84	13.18	3659	366	30	215,920
80-2	0.111	0.249	0.0276	80	131.84	13.18	3644	364	30	88,030*
80-3	0.111	0.249	0.0276	80	131.84	13.18	3644	364	30*	193,420*
80-4	0.112	0.250	0.0280	80	131.84	13.18	3692	369	30	167,070
75-1	0.111	0.249	0.0276	75	123.60	12.36	3416	342	30	208,750
75-2	0.111	0.249	0.0276	75	123.60	12.36	3416	342	30	481,420
75-3	0.111	0.249	0.0276	75	123.60	12.36	3416	342	30	384,370*
70-1	0.111	0.249	0.0276	70	115.36	11.54	3188	319	30	179,770*
70-2	0.111	0.249	0.0276	70	115.36	11.54	3188	319	30	624,240
70-3	0.111	0.249	0.0276	70	115.36	11.54	3188	319	30	347,730
70-4	0.112	0.250	0.0280	70	115.36	11.54	3230	323	30	507,370
66.5-1	0.112	0.249	0.0279	*66.5*	109.59	10.96	3056	306	30	3,000,000
66.5-2	0.112	0.249	0.0279	*66.5*	109.59	10.96	3056	306	30	341,990
66.5-3	0.112	0.249	0.0279	*66.5*	109.59	10.96	3056	306	30	3,000,000
66.5-4	0.112	0.250	0.0280	*66.5*	109.59	10.96	3069	307	30	3,000,000
SPECIMENS 80-2, 80-3, 75-3, AND 70-1 DID NOT FAIL IN LASER MARKED REGION										

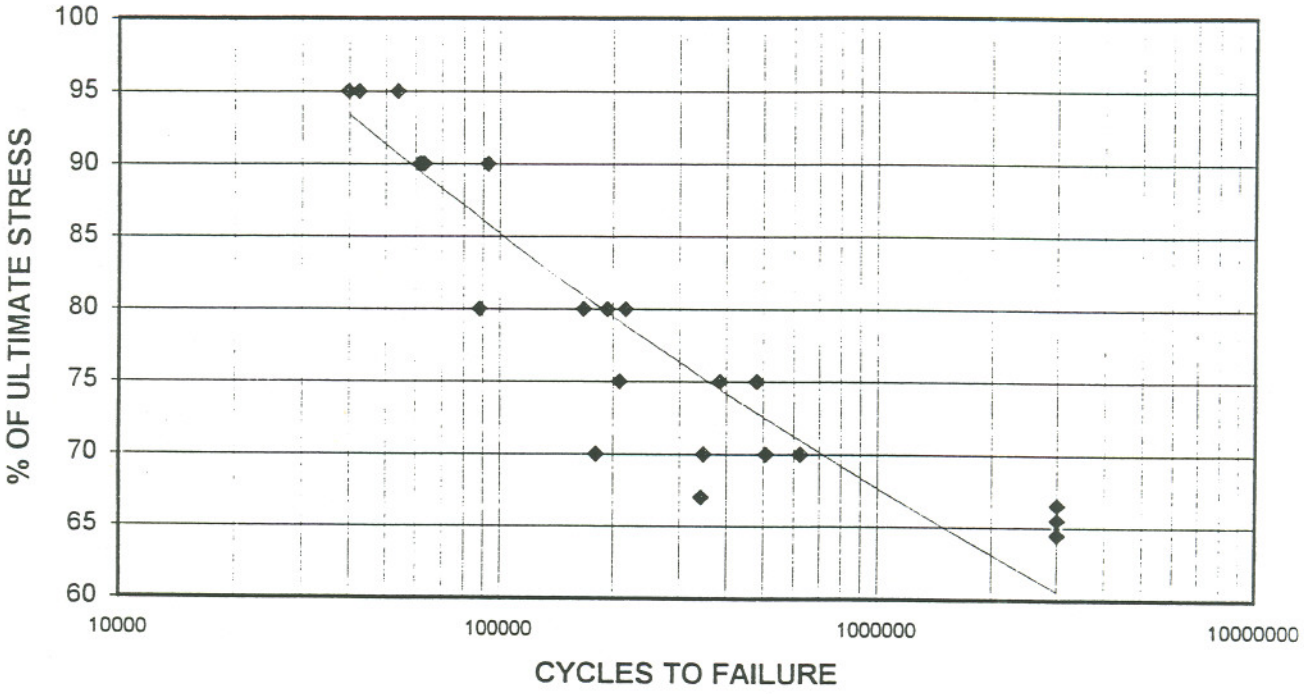


Figure 1 S/N Curve for 17-4 PH Stainless Steel with Laser Marking (R = 0.1)

Distribution;

B. Syms	D/284	FC 11
T. Wittman	D/284	FC 11
D. Sueme	D/248	AB 70
C. Silverman	D/284	AB 70